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COVER PICTURE

Testing an alternator rotor forging by ultrasonic means for internal faults. With this equipment, now in use at Witton, the probe travels the full length of the slowly rotating rotor so that 100 per cent coverage is guaranteed.

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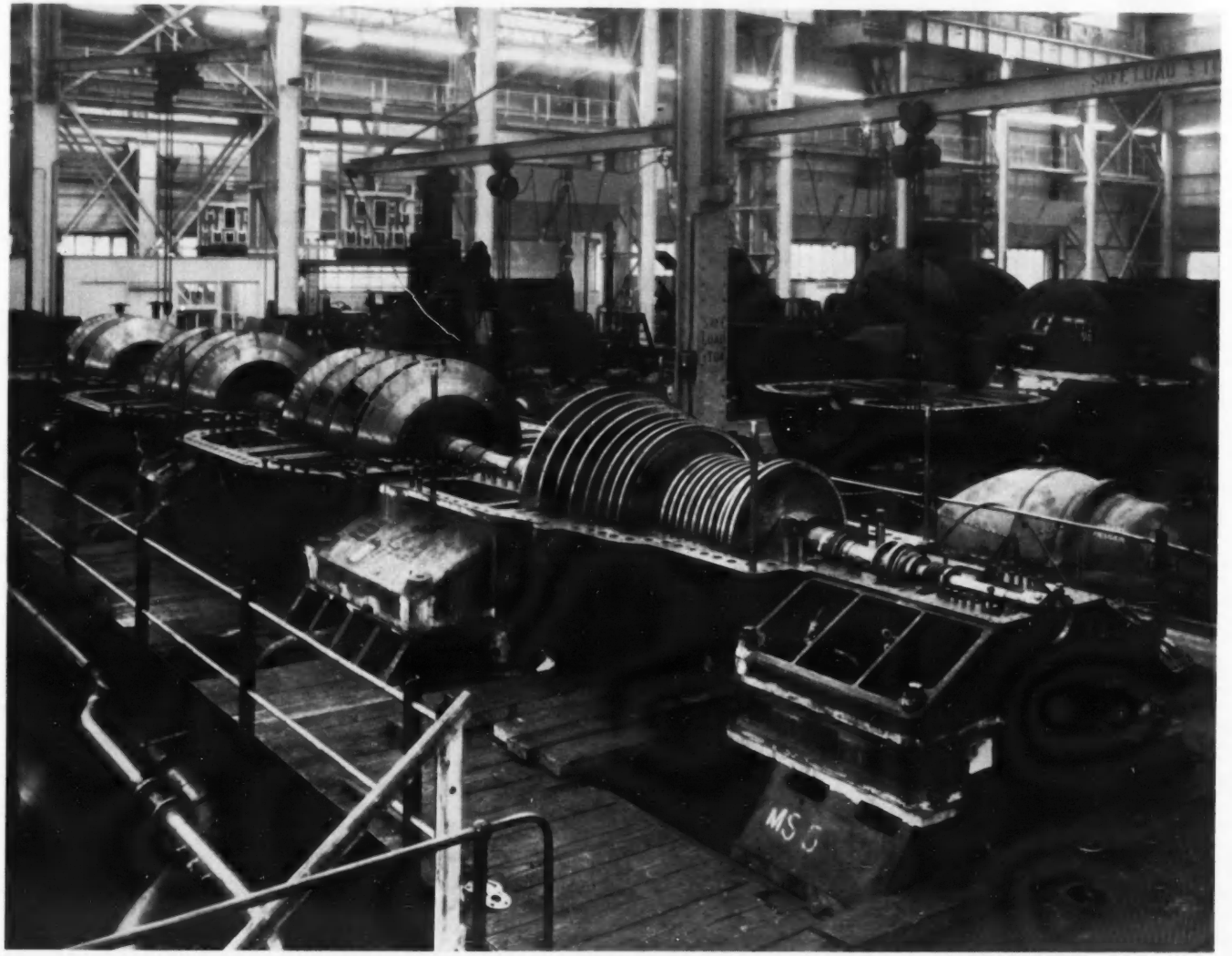


Erection of a centrifugal compressor for aeronautical research. The eight machines of this type will form a 352,000 h.p. installation, the largest of its kind in the world.

Electric Trains to Southend

By J. C. TURRALL, A.M.I.E.E., and W. E. LEWIS, A.M.I.E.E.,
Traction Department, Witton.

ALTHOUGH Brighton achieved wider fame from the patronage of the Prince of Wales, Southend-on-Sea had already become a fashionable resort for enjoying the recently discovered benefits of sea bathing by the end of the eighteenth century. Like Brighton, also, the rapid development of the town began when the railway made it easily accessible to all. The first railway route to Southend from London was through Barking and Upminster, but in 1889 the former Great Eastern Railway completed a branch to the town from Shenfield. When major plans for railway electrification were prepared in 1935, the Liverpool Street—Shenfield portion of this route was included, but the work was delayed by the outbreak of war in 1939 and the line was not electrified to Shenfield until 1949, when the conversion was carried out by the Eastern Region of British Railways on the 1,500 V d.c. overhead system. The whole of the substation equipment was supplied by the G.E.C., including 30,000 kW of mercury-arc rectifiers with all the associated 33 kV a.c. and 1,500 V d.c. switchgear. Electrification from Shenfield to Southend (Victoria Station) on the same system was undertaken in 1955 and the former steam service between Liverpool Street and Southend was replaced by electric trains on December 31 last year. In due course the whole line will be converted to the 25 kV single-phase system to conform with the similar conversion of the main line to East Anglia.

Today the County Borough of Southend-on-Sea embraces an area of 10,284 acres, including the adjacent resorts of Leigh-on-Sea, Westcliff, Thorpe Bay and Shoeburyness. Its population in mid-1955 was 154,800. Pleasure traffic alone on the two railway routes during the summer amounts to between three and four million visitors, but the County Borough also has many residents who travel to and from London or intermediate towns daily for business. Extensive housing development is taking place in areas north of the town through which the newly-electrified line runs, and the other places shown on the map (fig. 2) between Shenfield and Southend are extending similarly.

Fig. 1.—Two of the new four-car sets.

ROLLING STOCK.

A contract was placed with the G.E.C. for the electrical equipment of the thirty-two four-coach multiple-unit sets built by British Railways at Eastleigh for the Liverpool Street—Southend service. Each unit con-

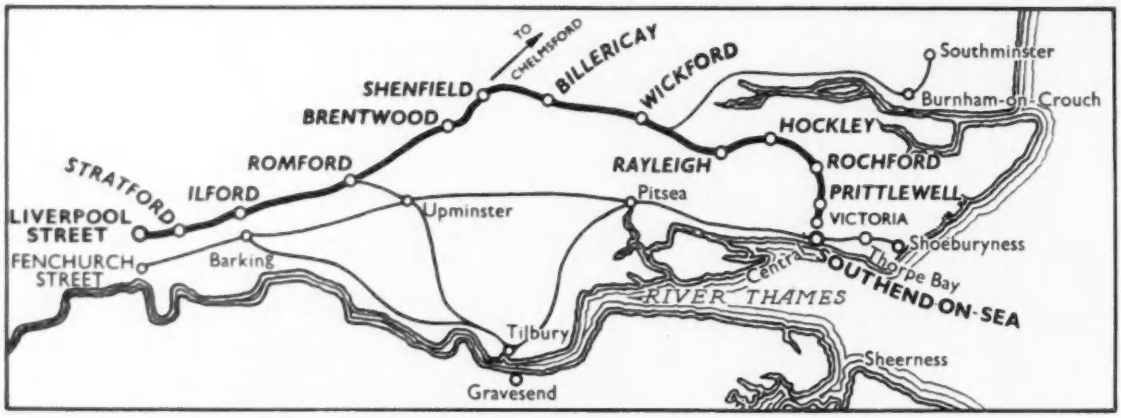


Fig. 2.—Railways between London and Southend-on-Sea.

sists of a driving trailer, motor coach, trailer and second driving trailer, providing in each unit 19 first class and 344 second class seats. Of the latter, 140 are in open type vehicles with central passageway and the remainder in compartment type coaches. First class sections of compartment coaches have side corridors. There are four toilet compartments in each unit, two in the trailer and two in the open third driving trailer. The combination of compartment and open type stock, with two classes, provides for the needs both of regular business travellers and of holiday visitors with their luggage.

There are some fairly steep gradients on the route between Liverpool Street and Southend. On the main-line section, Brentwood bank extends for nearly 4½ miles from Harold Wood to Ingrave, with two miles at 1 in 103 and a steepest section of about half a mile at 1 in 85 against down trains. The branch from Shenfield has a succession of switchback gradients, largely at 1 in 100, and trains to London face an unbroken climb at this inclination for three miles between Wickford and Billericay. Since electric traction was introduced the service has been accelerated considerably, some trains taking only fifty-five minutes for the 41¾ miles

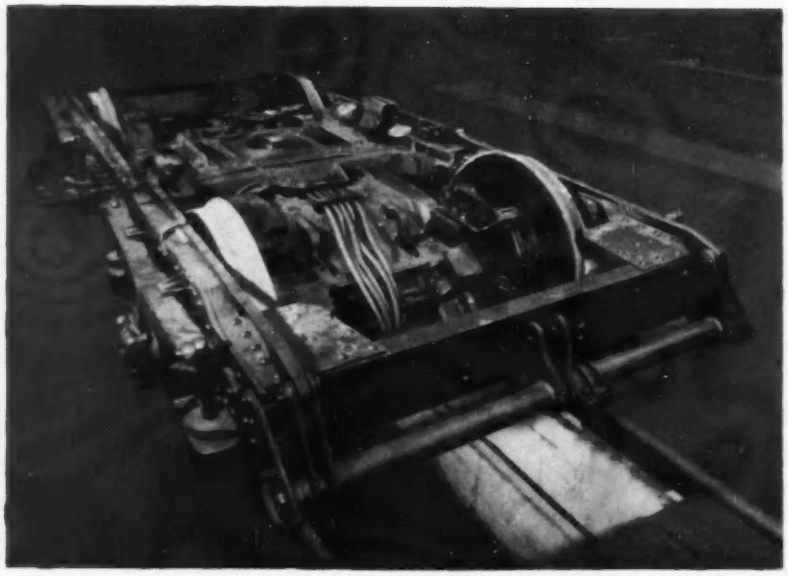


Fig. 3.—A motor bogie of the new multiple-unit stock.

from Southend to Liverpool Street with two intermediate stops. The frequency has also been greatly improved, the total of 119 trains on weekdays comparing with sixty-four previously.

MAIN POWER CIRCUITS.

In its principal features the equipment of the trains is similar to that of the eight three-car sets for the Manchester (London Road)—Glossop service.* Current is collected by a pantograph on the motor coach and passes to two overload relays, one in each leg of the four-motor equipment. The two axle-hung, nose-suspended motors in each bogie (fig. 3) are connected permanently in series, control being by series or parallel connection of the two pairs, with bridge transition. Either pair of motors can be isolated by means of hand-operated motor cut-out switches which also make the necessary modifications in the control circuit. Continuous and one-hour ratings of a unit are as below :

	Full field	*Weak field*
Continuous rating of unit	632 h.p.	696 h.p.
One-hour rating of unit	800 h.p.	880 h.p.

The motors are self-ventilated and take in cooling air direct through protected inlets on top of the frames.

The electro-pneumatic contactor control equipment, with the relays, reverser and motor cut-out switch, is accommodated in three cases (fig. 4) mounted in the motor coach underframe, and is operated from master controllers in the driving trailers, there being no driving compartment in the motor coach because of its intermediate position in the unit. Fig. 5 shows the interior of a driving compartment. A shunting notch and three running notches are provided, the former having a rating to permit shunting movements and other slow running with all resistance in circuit. Movement of the controller handle to the series, parallel or weak-field positions initiates automatic acceleration to the selected notch. One section of resistance is in circuit only on the shunting notch, followed by eight resistance notches in the automatic progression to full series and four to full parallel. During acceleration in parallel the corresponding sections of resistance in each motor branch are short-circuited together.

There is one weak-field running notch, but this is reached through an intermediate step in which a portion of the motor fields is diverted by resistances. In the final step the fields are weakened by tapping. To reduce the demand when taking the weak-field steps by keeping the current peaks within reasonable limits, a separate current limit relay is used, having a lower drop value than the main relay.

Two rates of accelera-

Fig. 5.—Driver's compartment in a driving trailer.

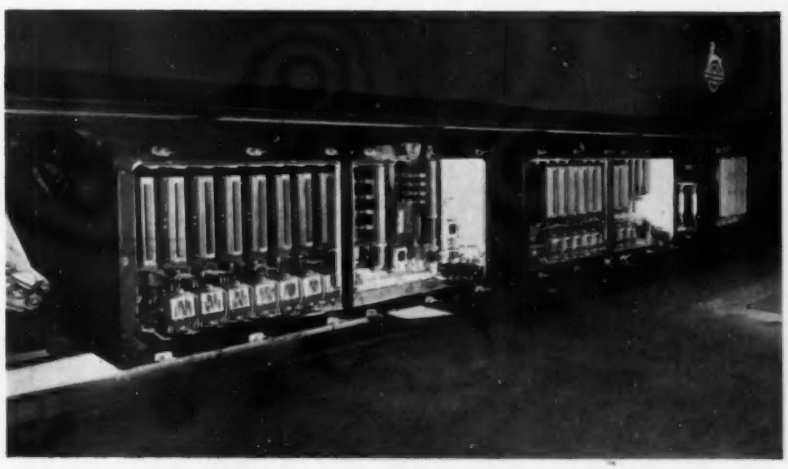


Fig. 4.—Equipment cases on motor coach underframe.

* *G.E.C. Journal*, Vol. 21, pp. 161-175, July, 1954.

tion can be selected by alternative "forward" positions of the reverser handle. The normal rate corresponds to 1·1 m.p.h.p.s., while the lower rate, intended for use in greasy rail conditions, is 0·85 m.p.h.p.s. When the higher rate is selected, the lift and drop values of the main and weak-field current limit relays are modified by means of shunt coils.

PROTECTION.

Operation of an overload relay opens the circuit by means of line contactors, a current limiting resistance being inserted before final rupture. When an overload relay trips, auxiliary contacts energise an indicating relay and cause a lamp to light in the van compartment (fig. 7) of the motor coach affected. This relay latches in, so that the lamp is not extinguished when the overload relay is reset by pushbutton from the driving cab, and remains alight to identify the faulty unit (provided the train line key switch is in position) until the indicating relay has been reset by hand.

In the event of a supply failure a no-current relay opens all line switches and contactors. The equipment will re-notch automatically to the condition dictated by the position of the master controller handle when the supply is restored.

In the main contactors the butt contact interlocks, under "Perspex" protective covers, and the electro-pneumatic valves are mounted at the front so that both are accessible when the front covers of the equipment cases are removed. The trains are equipped with a new design of control receptacles and jumpers using butt contacts, designed to simplify coupling up of trains and to ensure good contact at all points and positive locking of the jumper in position.

Fig. 7.—L.T. equipment cubicle in motor coach van compartment, showing pantograph foot pump in operating position.

AUXILIARY SERVICES.

The auxiliary supply to the motor-generator set, the Westinghouse Type CM38 compressor and coach heater lines is taken from the pantograph through a 60 A main auxiliary fuse, which provides back-up protection should the compressor contactor, M.G. fuse or heating fuse fail to clear. Fault currents in the auxiliary machines are limited by a protective resistance. A 20 ohm resistance on the negative side of the compressor motor limits its starting current. This machine and the M.G. set (fig. 6) are started direct to line, through all-electric contactors. A resistance having part of its value on the positive side of the M.G. set motor and part on the negative side provides stability for through currents, as at starting; the positive section limits the fault current in case of a flashover to earth in the machine. The input to the motor at 1,350 V is 10·1 amp at 1,625 r.p.m.

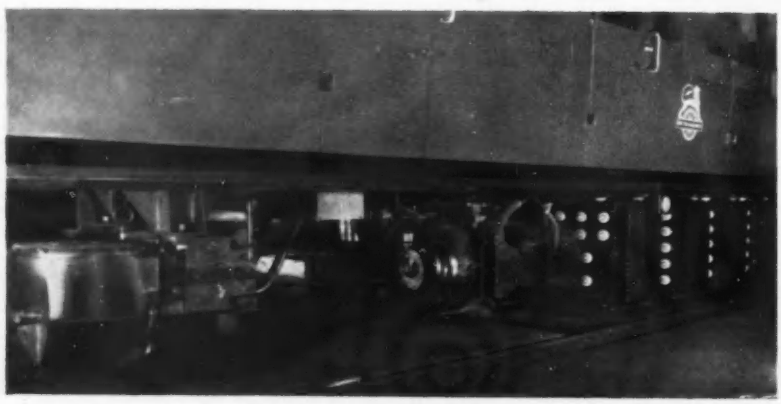


Fig. 6.—Compressor, motor-generator set and main resistance cases.

The L.T. generator is rated at 9·5 kW (52 V, 183 amp continuous) and provides an output, controlled by a carbon pile voltage regulator, for the control circuits, battery charging, train lighting and water heating. Series turns are provided on the voltage

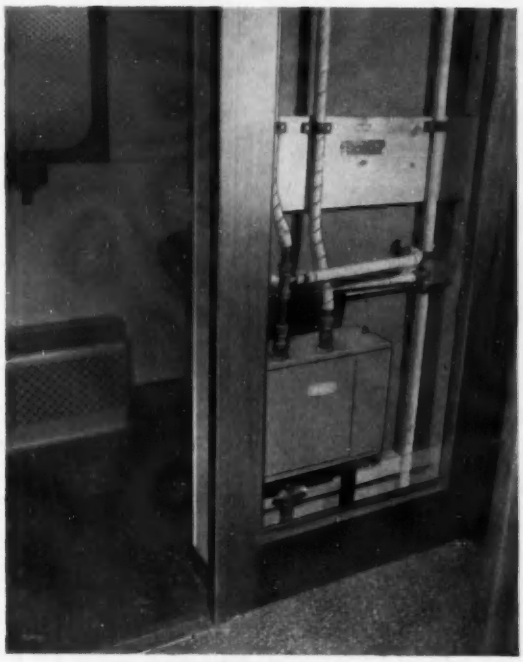


Fig. 8.—1½ kW water heater and toilet compartment heater.

regulator to give an overall decompounding characteristic so that the voltage is reduced and the charging current restricted if the battery is in a low state of charge.

A feed is taken through a main water heater fuse to the bus line supplying the four 1½ kW, 1-gallon water heaters (fig. 8) in a train unit. The water heaters are thermostatically controlled via contactors in underframe equipment cases which also house local isolating switches for each pair of water heaters and individual circuit fuses. The 1-gallon capacity inner container of the water heater is constructed of copper sheet, with welded seams, and is tested to 6 lb. per sq. in. It is fully thermally insulated on all sides and enclosed by a mild steel sheet outer casing, to which it is bonded electrically. The element assembly consists of two 52 V, 750 W sheathed wire elements brazed to a hard brass plate which carries a two-way terminal block. It is fitted to the container by a watertight joint and can be removed complete by unscrewing two fixing nuts on the element plate and screwing two screws inwards to break the joint. The terminal block is a separate item, screwed to a bracket on the element plate, and can be transferred to a new element assembly when replacement of the latter is necessary.

A 7 in. A.C.S. pattern thermostat is secured by a spring clip in a tinned copper pocket which is made watertight to the heater during manufacture. The thermostat is removable without draining the heater. A special locking device is fitted to lock the setting at 120 deg., 140 deg. or 160 deg. F. The complete heater is Admiralty shock-tested.

Each motor-generator set supplies the lighting in its own four-coach unit. A lighting main fuse provides overall protection, but sub-circuit fuses protect the individual coach lighting groups. Train lighting is controlled by a contactor which incorporates set and trip gear.

A Nife 55 amp-hr. Type ES5 alkaline battery is carried on the underframe of the motor coach and will supply the control and essential marker lights of a twelve-car train for some two hours. It is not required to maintain emergency coach lighting.

Fig. 9.—Pantograph on motor coach roof.

PANTOGRAPH OPERATION.

A cubicle containing the majority of the L.T. control equipment is housed in a van compartment in the motor coach. A foot pump for raising the pantograph is also housed in the cubicle and can be hinged down into the operating position after the door has been opened. When the pantograph is raised by the pump, the auxiliary relay which completes the circuit for closing the compressor and M.G. contactors is set by hand, so that the machines start as soon as the pantograph touches the overhead line. When air is available, however, the pantograph is raised by pressing the "panto up" pushbutton in the driving trailer, this action closing the auxiliary relay electrically. On operating the "panto down" pushbutton in the driving trailer, the auxiliary relay is tripped ; its contacts de-energise the heater, M.G. and compressor contactors so that the possibility of breaking current at the pantograph pan is precluded. If for any reason it is necessary to shut down the motor generator set from the van position, the isolator in the equipment cubicle can be opened to de-energise the M.G. contactor. The installation of a pantograph on the roof of a motor coach is shown in fig. 9.

Fig. 10.—500 W heaters in an open type coach during construction.

The 1,500 V supply to the train heating lines is taken from the negative side of the main auxiliary fuse through a contactor and a fuse for each line. The carriage heaters (fig. 10) fitted under the seats, are rated at 500 W and are connected five in series. Passenger heaters are thermostatically controlled by a thermostat in the motor coach.

Each heater contains an Alumbro-sheathed element of double-hairpin shape, rated at 500 W, 300 V. The heater is insulated for a voltage to earth of 1,500, secondary insulation being provided in the form of glazed porcelain insulators. An outer casing of 14 gauge mild steel encloses the element and is bolted to the terminal box body, which has a removable top cover for access to the connections. Fixing plates for floor mounting are integral with the terminal box at one end of the heater and with the casing at the other end. The element slides into the casing, in which it is correctly located by guide plates. If replacement is necessary, an element can be withdrawn after unbolting the casing from the terminal box and removing the terminal box mounting bolts.

A bell communication system is provided between driver and guard, pushbuttons and a bell being provided in the van and at all driving positions.

ACKNOWLEDGMENTS.

Valuable co-operation was received in the preparation of this article from the Public Relations and Publicity Department of the Eastern Region, British Railways, and from the Publicity Officer of the County Borough of Southend-on-Sea.

Propulsion Equipment of the Royal Research Ship "John Biscoe"

By C. SMITH, A.M.I.E.E., M.I.Mar.E.,
Manager, Marine Department
and J. G. F. DERRINGTON, A.M.I.E.E.,
Witton Engineering Works.

Fig. 1.—The Royal Research Ship "John Biscoe".

THE "John Biscoe", the first vessel ever designed and built specially for scientific work in Antarctic waters, was launched at Paisley, Scotland, on June 11, 1956, and successfully completed her trials on the River Clyde some five months later. Built for the Falkland Islands Dependencies Survey by Fleming & Ferguson Ltd., the new "John Biscoe" is a diesel-electric ship of 2,250 tons displacement specially constructed and equipped for navigation in ice. At the launching ceremony, which was carried out by Lady Patricia Lennox-Boyd, wife of the Secretary of State for the Colonies, it was officially announced that the Queen had granted permission for the new vessel to be designated a Royal Research Ship. The R.R.S. "John Biscoe" (fig. 1) is commanded by the Senior Master of the Dependencies Survey, Captain William Johnston, and sailed from Southampton on her maiden voyage to the Antarctic on November 26.

On New Year's Day, 1957, when south of the Antarctic Circle, the ship kept a rendezvous with the Royal Yacht "Britannia" and was joined by the Duke of Edinburgh, who sailed in her through the ice-infested waters to visit a base on the coast of Graham Land. This was the furthest point south reached by the Duke in the course of his Commonwealth tour.

The Falkland Islands Dependencies—the most important of which are South Georgia and the Antarctic territories of the South Shetlands, the South Orkneys, and Graham Land—lie in the South Atlantic Ocean and consist of a number of groups of islands together with part of the mainland of the Antarctic continent (fig. 2). The majority of the Antarctic regions are almost completely covered with snow and ice, and are virtually destitute of plant life. In these desolate surroundings the Dependencies Survey has

Fig. 2.—The Falkland Islands Dependencies Group and part of the Antarctic continent.

succeeded in establishing ten permanent bases where some seventy-six men spend periods of up to two years carrying out important scientific and meteorological work; each of these units is contributing scientific information during the period of the International Geophysical Year 1957/58. In the Antarctic summer the ice clears sufficiently for a specially strengthened ship to carry relief staff, supplies and equipment to the bases, the round trip from Southampton covering a distance of about 27,000 nautical miles, and it is for this purpose that the Royal Research Ship "John Biscoe" has been built.

The new ship takes its name from the Antarctic explorer who commanded the British expeditions of 1830-1832 in the ships "Tula" and "Lively". He circumnavigated the Antarctic continent and annexed part of it in the name of King William IV, calling it Graham Land. The first ship to be named "John Biscoe" was a converted naval net-layer which carried out relief duties for the Survey from 1947, but has now been sold and the name transferred to her successor.

The new "John Biscoe" has been constructed to the design of the consulting engineers, Graham & Woolnough, of Liverpool, in conjunction with the Crown Agents, personnel of the Falkland Islands Dependencies Survey and the shipbuilders. She is powered by two National diesel engines and is fitted with electric propulsion and control equipment ordered by J. Charters of Glasgow and supplied by The General Electric Co. Ltd.

ICE-BREAKER CONSTRUCTION.

The ship has a designed loaded displacement of 2,250 tons at a draught of 16 ft. Overall length is 220 ft., and the service speed 12 knots. The construction is in accordance with the requirements of Lloyds Register of Shipping, and many special features are incorporated to facilitate navigation in the Antarctic. The bows are of the ice-breaker type, the ship having a raked forefoot which allows her to slide up on the ice and break it with her own weight. The hull is plated with Coltuf 28, a toughened steel specially suitable for ice conditions; for about 40 ft. from the bows this skin plating is 1 in. thick, while $\frac{3}{4}$ in. plate is used for the rest of the hull. The main frames are supplemented by intermediate frames to provide

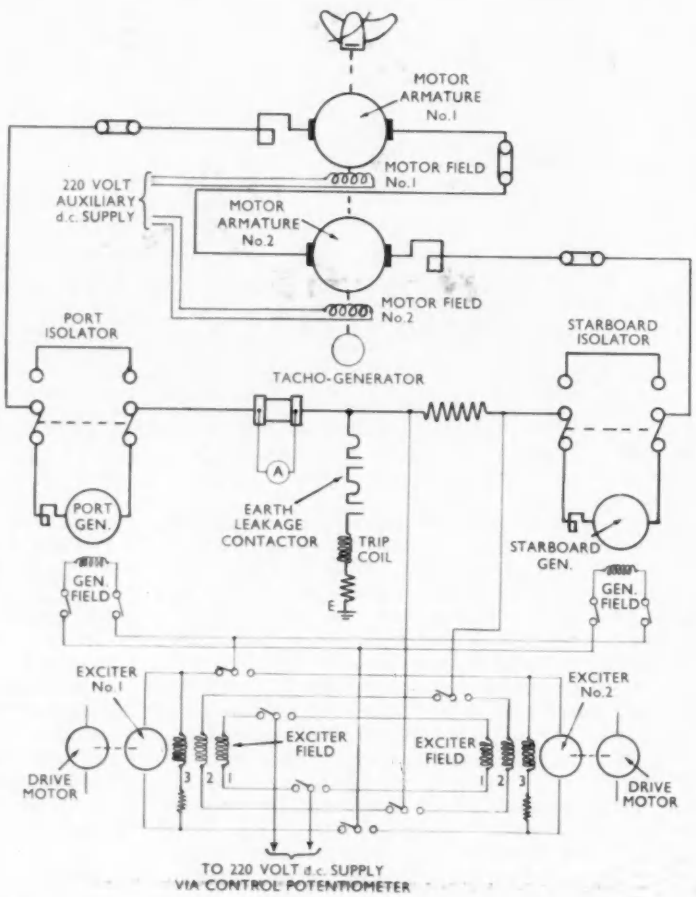


Fig. 3.—Simplified schematic diagram of the electric propulsion equipment.

additional strength, and heavy fins are fitted to protect both hull and rudder from ice. The steering gear is electrohydraulically operated, and provision has been made to counteract possible disabling of the gear should the rudder ground on a submerged obstruction.

Accommodation is provided for thirty-three officers and crew and for a scientific staff of thirty-four. The quarters afford a high standard of comfort, special consideration having been given to insulation against the extreme cold of the Antarctic, and, as the ship will sail through the tropics to reach her destination, a mechanical system of ventilation has been installed to provide either hot or cold air as desired. Ample cargo space has been provided and two electrically-operated 10-ton derricks are installed to serve the forward hold, together with a 3-ton derrick for the victualling stores and cargo stowed aft.

PROPULSION SCHEME.

The two 8-cylinder diesel engines are each directly coupled to a d.c. generator. A reversible d.c. motor drives the propeller shaft, the speed of rotation being raised from rest to approximately half-speed by increasing the field strength of the main generators, and consequently raising the voltage of the supply to the armature of the propulsion motor. Speeds in excess of half-speed are obtained primarily by an increase of engine speed, though simultaneous adjustments are made to the generator fields to compensate for the large increase in output. A schematic diagram of the propulsion equipment is shown in fig. 3.

The excitation supply for the main generators is provided by one of two motor-driven control exciter sets (fig. 4), each of which is capable of providing the full excitation for both generators. Each exciter is fitted with three field windings, the first of which is connected to the ship's 220 volt d.c. auxiliary supply through a control potentiometer which combines the functions of a reversing switch and regulator. The speed and direction of rotation of the propulsion motor are controlled by means of this potentiometer, which is easily operated as it is carrying only the relatively small current flowing in the exciter field winding. The second field, which is connected across a resistor in the main motor armature/generator armature loop circuit, is a differential compound winding which causes a pronounced "droop" in the output characteristic of the main generators, thus affording protection against very rapid operation of the speed control on the main desk. The third field winding, which is self-excited, is provided to ensure stable operation of the system.

The field windings of the propulsion motor are separately excited from the ship's auxiliary supply and, when using only one engine and generator, the field strength is automatically adjusted to enable an economical speed to be obtained. With this system of control the changeover from one to two engines or vice versa can be accomplished so easily and quickly that the ship can be restored to full power before it has lost way from the original power condition. In addition, the fuel consumption is restricted to a minimum when running at very slow speeds, while a speed of 180 r.p.m. is available at the propeller shaft to meet emergency conditions.

DIESEL ENGINES.

Each of the two main generators is powered by a National eight-cylinder, four-stroke, pressure-charged F4AU8 diesel engine (fig. 5), running at 500 r.p.m. The engines have a bore and stroke of 12 in. and 15 in.

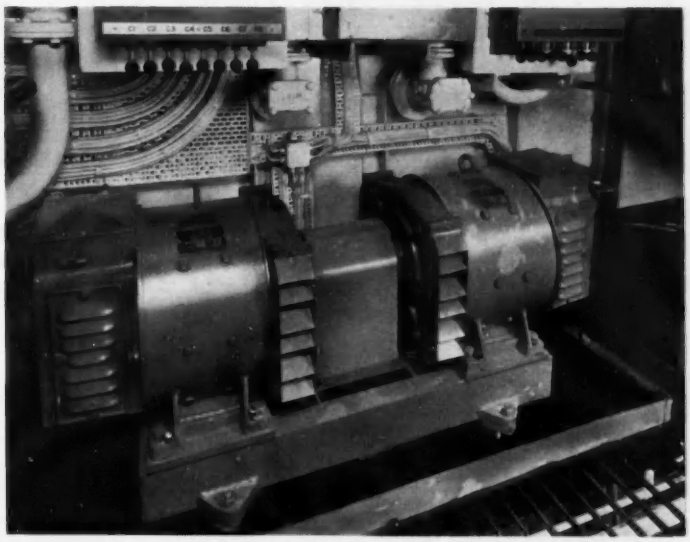


Fig. 4.—The port control exciter set.

respectively, and the design embodies cylinder heads of the four-valve type with controlled turbulence, giving high thermal efficiency and good combustion at all loads. Napier exhaust pressure-chargers are fitted to each engine.

Each set is mounted on a substantial fabricated steel underbase and the whole structure is carried on resilient mountings which consist of Tufnol blocks interposed between the combined underbase and the ship's seating. This material is also fitted in the form of collars around each holding-down bolt and is used also as locating chocks at the ends and sides of the baseplates. The engines are a handed pair, the fuel-pumps and controls being arranged inboard, and a hinged platform is fitted to facilitate maintenance when necessary. At all other times the platform is kept up to provide maximum gangway space. The

Fig. 5.—The starboard propulsion set of the "John Biscoe" leaving the National Works.

main bearings are water-cooled, thus cooling the lubricating oil as well and obviating the necessity for an oil-cooler.

Control of the engines is carried out by means of motor-driven speeder gears operated from the engine-room control panel, and an electric tachometer transmits the engine speed to indicators mounted in the engine room and on the bridge of the vessel. The fuel and lubricating oil filtering arrangements are ample, consisting of magnetic filters in addition to metal disc and felt element filters. Each engine has a dry sump with motor-driven oil pumps, while a cylinder lubricator ensures a supply of clean oil to the cylinders. The engine cooling water is circulated by means of motor-driven water pumps through two tubular heat exchangers, each of which is capable of dealing with the total heat dissipation of the main and auxiliary engines.

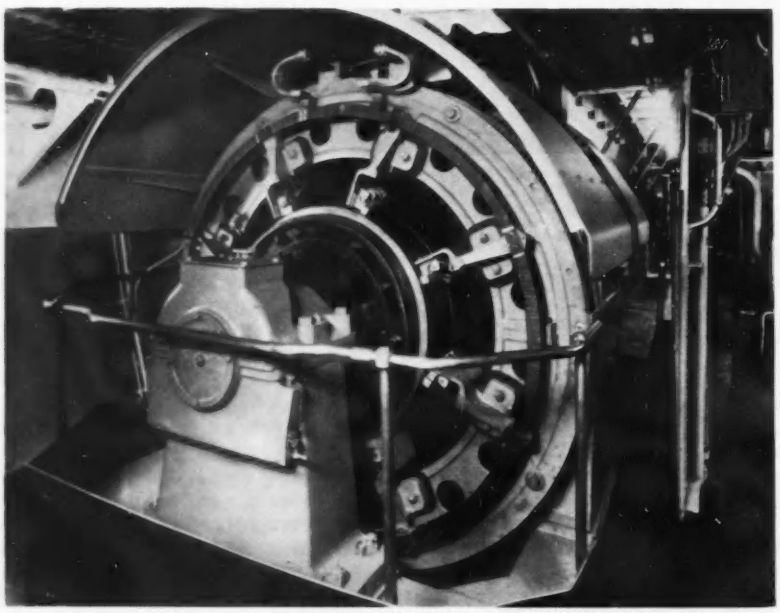


Fig. 6.—640 kW port main generator.

Acoustic hoods are fitted over each engine to reduce the noise level in the engine room. The behaviour of the engines during the sea trials of the ship proved eminently satisfactory, and observation of the exhaust gases from the funnel did not reveal any change of load; indeed, it was almost impossible to see the exhaust during any of the power conditions under which the engines were required to operate.

ELECTRICAL MACHINERY AND CIRCUITS.

The two main generators, one of which is shown in fig. 6, are rigidly coupled to

the diesel engines and are of identical pattern, each providing a maximum output of 640 kW at 600 volts when driven at 500 r.p.m. The machines are of the open type with drip-proof canopies, and are fitted with disc-lubricated journal bearings. As already described, excitation is provided by separately driven control exciter sets and the generators are designed to give full output at speeds varying slightly from the normal maximum speed of 500 r.p.m. This feature enables the engine speed to be adjusted so as to cause minimum vibration in service.

The double-armature propulsion motor (fig. 7 and 8) has a normal full-load output of 1,350 h.p. at 175 r.p.m. with an emergency maximum rating of 1,450 h.p. at 180 r.p.m., and is fitted with a Michell water-cooled combined thrust and journal bearing at the driving end and with a disc-lubricated journal bearing at the opposite end of the shaft. In view of the reversing duty, the motor has been designed to run sparklessly at all loads with fixed brush positions.

Each armature has its own field winding, the two armatures being connected in series and the field systems in parallel, while a special arrangement of terminals and links is provided to enable either armature to be run separately under emergency conditions. Cooling is provided by a 30 in. two-stage Aerofoil contra-rotating fan mounted in trunking at the top of the magnet frame. Each stage of the fan is hinged and can be swung clear for inspection or maintenance. The rating is such that a single stage is sufficient to supply cooling air for the motor under normal full-load conditions.

The whole of the switchgear associated with the propulsion equipment is housed in two cubicles and a control desk, all of which are located in the engine room. Each cubicle houses the switchgear for one

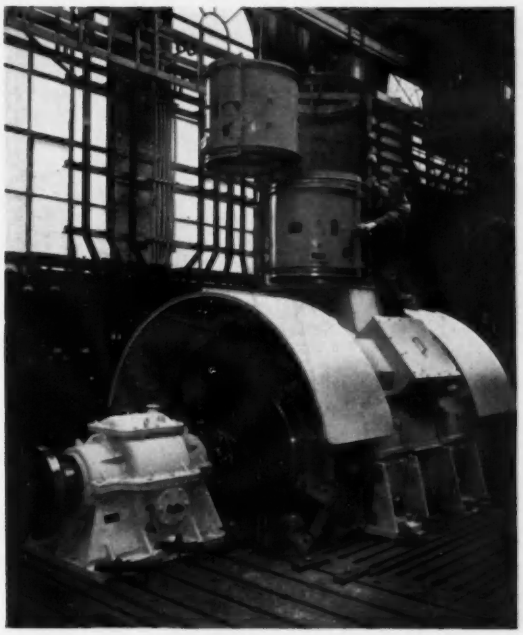


Fig. 8.—Main propulsion motor complete with ventilating fans on test.

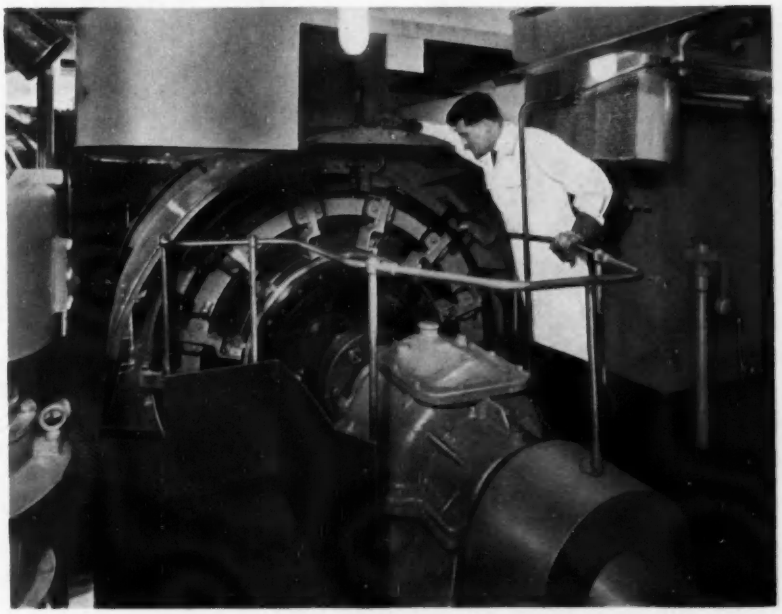


Fig. 7.—1,350 h.p. main propulsion motor in the engine room.

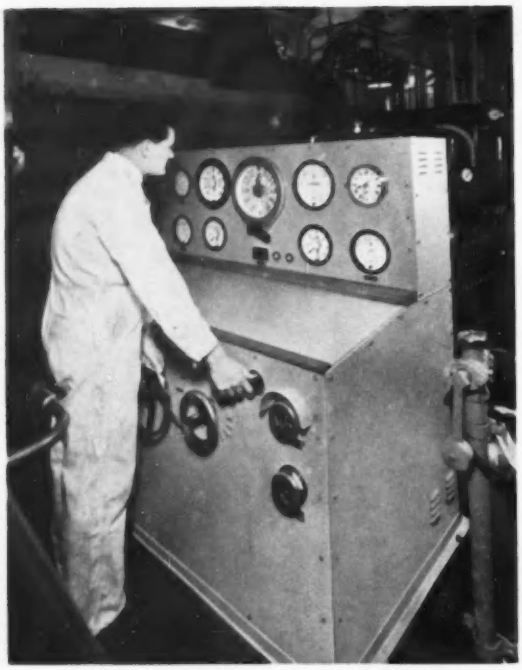
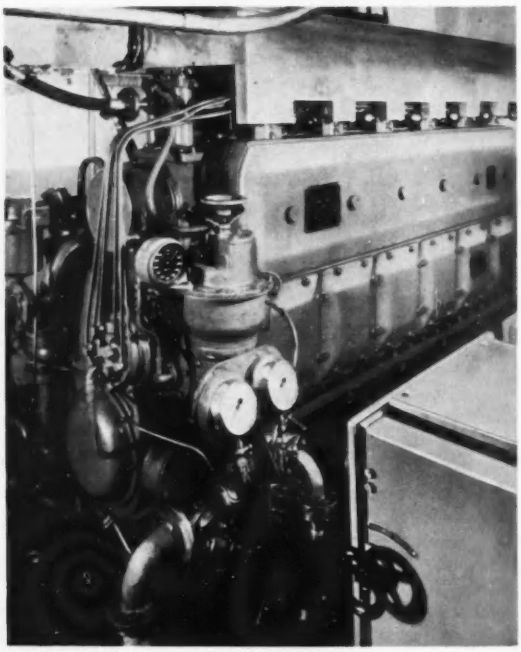


Fig. 9.—The main control desk.

main generator, including the isolating and by-pass switches which enable the generator to be connected to or isolated from the main motor armature/generator armature loop. The main isolating switch is operated by handwheel from the front of the cubicle, and a solenoid-operated mechanical interlock is fitted to prevent operation unless the control on the main desk is in the " off " position. Each cubicle is equipped with an under-speed relay which gives audible warning if the speed of the associated generator falls appreciably below the normal half-speed of 250 r.p.m.

An earth-leakage relay and contactor for the main loop circuit are provided in the starboard isolator cubicle. The earth contactor is normally hand-operated and, when latched in, connects the centre point of the main loop circuit through the trip coil to earth, so that no part of the loop circuit can be at



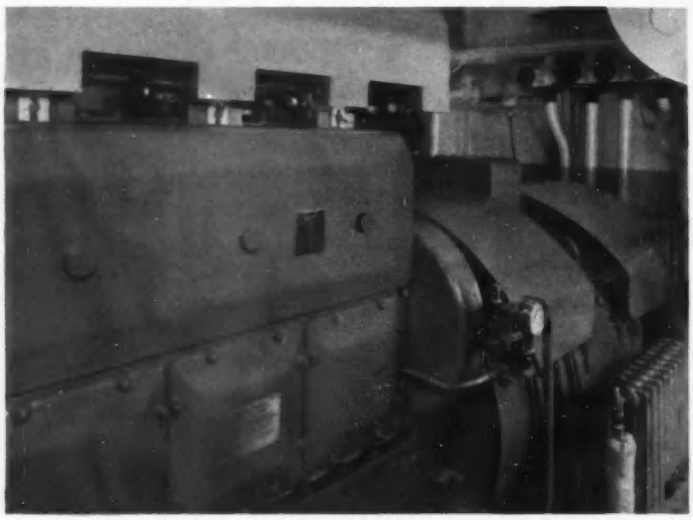


Fig. 10 (above).—The control end of the port auxiliary engine, showing the acoustic hood to reduce the noise level in the engine room.

Fig. 11 (left).—One of the 200 kW auxiliary generator sets.

more than the voltage of one generator above earth. Should an earth fault occur at any other point in the loop circuit, the fault current through the trip coil will cause the relay to operate and isolate the normal earthing, leaving only one connection to earth, so that the operation of the propulsion equipment will not be interrupted by the fault. At the same time, an alarm is sounded to notify the engineer on watch, who can then make arrangements to have the fault rectified when it is convenient to stop the engines.

CONTROL SYSTEM.

The control desk (fig. 9) contains the main speed control unit, a vernier speed control unit, the excitation contactors for the main motor and generator, and the potentiometers controlling the fields of the exciters for the main generators. Mounted on a vertical panel at the top of the desk and facing the operator are the receiver unit of the bridge telegraph and the speed indicators for the propulsion motor and the main engines, together with voltmeters for each of the main generators. To the left of the main control wheel is a changeover switch which enables the operator to select one of the two control exciter sets ; this switch is fitted with mechanical interlocks to prevent operation unless the main control is in the " off " position.

The main speed control takes the form of a hand-wheel which is rotated clockwise for speeds ahead and anticlockwise for speeds astern. Eight notches are provided for each direction of rotation, the last notch corresponding to the emergency overspeed condition. On the first four notches of the control the main engines run continuously at half-speed and the speed of the propulsion motor is varied electrically in the manner already described. A vernier control, which is effective only on these four notches, enables the operator to select four points of fine speed regulation between each pair of notches. On notches 5, 6 and 7 the control wheel simultaneously adjusts the speed of the main engines and the excitation of the main generators to secure the required speed of rotation of the propeller shaft. The engine speed is not increased when moving the control wheel to notch 8, as the emergency maximum speed is obtained by weakening the field of the propulsion motor.

The engine room receiver unit serves to communicate orders from the bridge to the engineer on watch, and has no direct control over the propulsion equipment, but if the control wheel is moved in the opposite direction to that specified in the order already acknowledged, a " wrong way " alarm will sound before any movement of the propeller motor can take place.

Fig. 12.—Group starter switchboard.

AUXILIARY AND EMERGENCY SUPPLIES.

In addition to the propulsion equipment already described, the National Gas & Oil Engine Co. Ltd. has supplied the engines for the auxiliary power supplies, and the G.E.C. the corresponding electrical plant. The two 200 kW auxiliary generators, one of which is shown in fig. 11, are driven by two National R4A6 diesel engines. The engines are four-stroke, normally-aspirated units with a bore and stroke of 9 in. and 12 in. respectively, and run at 600 r.p.m. Like the main engines, these are a handed pair with controls and fuel pumps inboard, resiliently mounted on combined underbases, and fitted with acoustic hoods (fig. 10). Integral lubricating oil and water pumps are installed and provision is also made for lubricating oil and water services to be obtained from the main engine supply. A separate lubricating oil

cooler is not necessary as the main bearings are water-cooled, but an auxiliary heat exchanger is fitted for use when the main engines are not in operation.

The emergency generating set was supplied by J. & H. McLaren Ltd., and comprises an M2 44 b.h.p. engine driving a 20 kW generator and an air compressor with a capacity of 16 c.f.m., F.A.D. The unit is radiator-cooled with a separately-ducted air supply and starting is achieved either by air-in-cylinder or by Berger Hand-draulic starter.

The G.E.C. has also supplied for the " John Biscoe " the main switchboard, the group starter switchboard (fig. 12) and motors and starters totalling approximately 200 h.p. for engine room auxiliary drives, together with the engine room fans. The group starter switchboard consists of standard pressed steel cubicles combined to form a multi-panel board of compact arrangement which facilitates maintenance and saves space.

The galley (fig. 13) was also equipped by the G.E.C., the installation including a double-oven range, steaming oven, griller, fish fryer and water boiler. Lighting throughout the accommodation in the ship is by G.E.C. fittings, and the Company also supplied quantities of cable and installation accessories.

Acknowledgment is due to Fleming & Ferguson Ltd., and to the Falkland Islands Dependencies Survey for permission to obtain photographs of the " John Biscoe " and to publish this description of the ship.

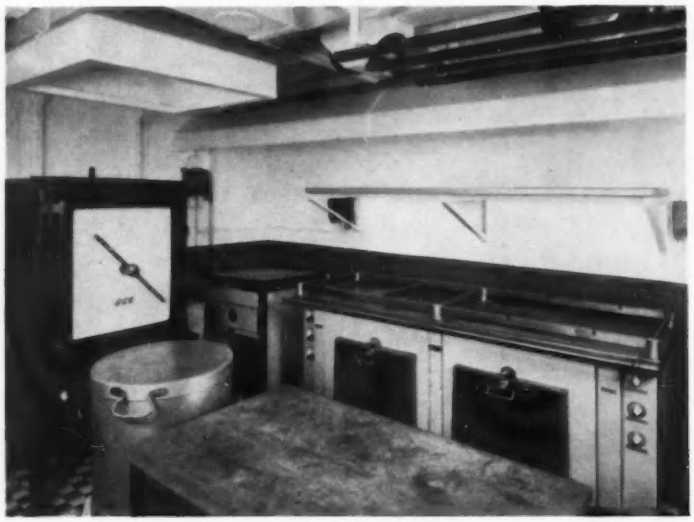


Fig. 13.—The galley.

D.C. Winding Equipment at Silverwood Colliery

By C. A. MAER,
Witton Engineering Works.

Application of control exciters to the Ward Leonard principle provides an extremely sensitive system with, perhaps, the highest accuracy of speed control commercially attainable. This is a closed-loop control, a controlling input signal proportional to the desired speed being compared with a signal proportional to the quantity actually obtained from the system output. Any discrepancy in these two quantities corrects continuously the output quantity to the desired degree of accuracy.

As part of the extensive programme for modernising the coal industry in this country, the National Coal Board placed contracts with The General Electric Co. Ltd. for the supply and erection of two geared Ward Leonard d.c. winders for Silverwood and Cadeby Collieries in the North Eastern Division. The mechanical parts were built at the Company's Erith Works and the motors, with all the associated control gear, were designed and manufactured at the Witton Engineering Works.

These installations are of particular interest in that they represent the first application to d.c. winders of the G.E.C. system of speed control embodying control exciters, which have been used with marked success for various drives in steelworks, notably those of the temper mills at the Trostre and Velindre Works of the Steel Company of Wales.

In this article the winder at the East Shaft of Silverwood Colliery is described and illustrated but the information applies equally to the equipment in service at No. 2 shaft of Cadeby Colliery.

THE WINDER.

The winder (fig. 1) is designed to raise 525 tons of coal per hour from a depth of 2,299 ft. and is driven through single-reduction double-helical gearing by a d.c. motor rated at 3,700 h.p., 0/320 r.p.m. The 0/650 volt d.c. supply is provided by a 2,650 kW Ward Leonard set (fig. 2), of which the 11 kV synchronous driving motor is started by the reactor method.

There are two parallel drums, 18 ft. dia., one of

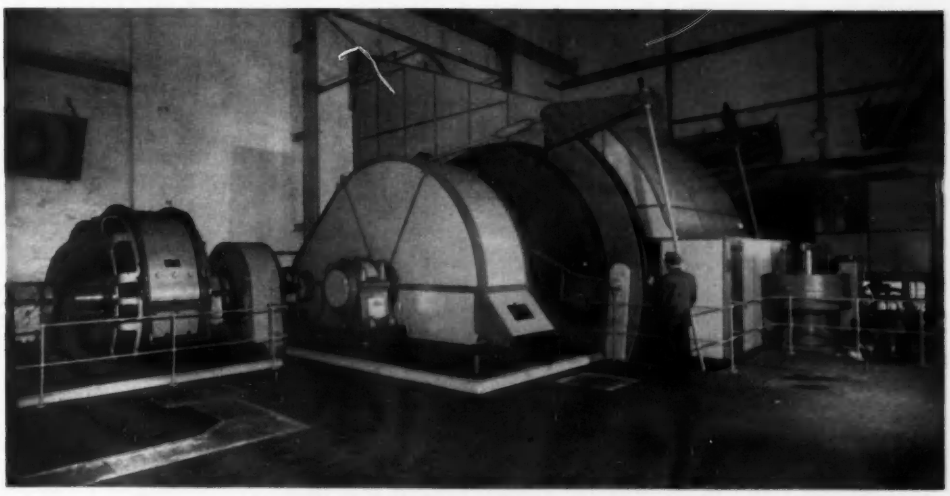


Fig. 1.—3,700 h.p. geared d.c. winder at the East Shaft.

which is clutched and the other fixed on the drum shaft. An interesting feature is the method of rope grooving employed, whereby the rope is laid across the drum during coiling on the first layer. This grooving is designed to eliminate the undesirable effect of " rope flap ", as experienced with the normal series of parallel grooves which have hitherto been employed for multi-layer coiling.

The mechanical brakes (fig. 3) operate on a variable-pressure principle. Experience on winders at various collieries using brakes of this type extends over a number of years and in all cases brake performance has been consistently satisfactory.

This brake system consists, essentially, of two brake engines, one being a double-acting pressure engine which, for normal operation, applies both sets of brakes ; and the other a standard weight type brake engine, which, in the event of changing winding levels, applies the loose drum brake so that the clutch can be withdrawn. The clutch engine and weight brake engine are interlocked so that it is impossible to withdraw the clutch until the loose drum brakes are fully applied, or to release the brakes until the clutch is engaged.

The rate of application of the brakes during the high-speed period of the wind is controlled by a slow braking valve which is operated by cam gear and restricts the flow of oil from the brake engine. Rapid application of the brakes is possible during the acceleration or retardation periods.

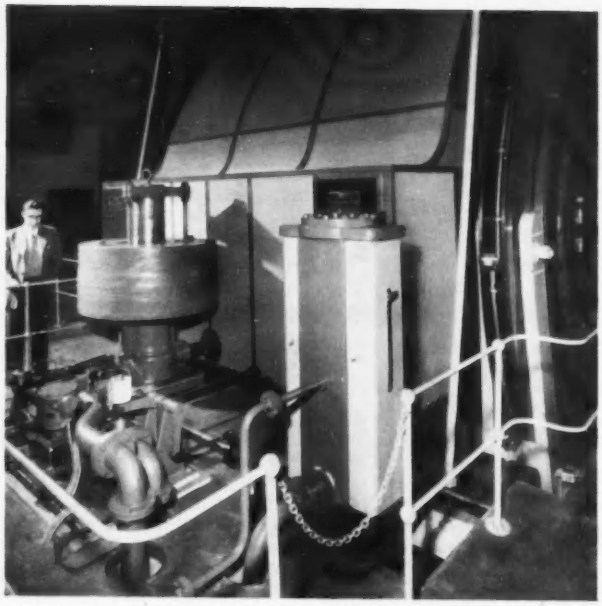


Fig. 3.—Mechanical brake-operating gear of the variable-pressure type.

SPEED CONTROL SYSTEM.

Speed control of the winder is achieved by the control exciter system which combines the most desirable features of the " three-field " generator with those of the straight Ward Leonard arrangement.

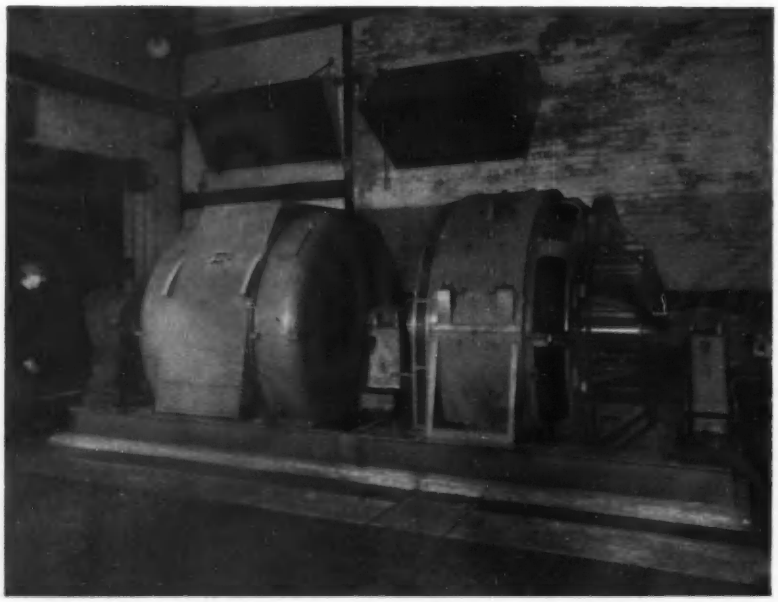


Fig. 2.—2,650 kW Ward Leonard set.

It is simple to operate and maintain and is extremely sensitive, giving, perhaps, the highest accuracy of speed control commercially attainable.

The control exciter system differs fundamentally from earlier methods of control in that it is a closed-loop system in which a controlling input signal proportional to the required speed is compared with a signal proportional to the quantity actually obtained from the system output. Any discrepancy in these two quantities corrects continuously the output quantity to the desired degree of accuracy. Since speed and voltage are closely related in large d.c. motors, the system as applied to winders depends basically upon voltage control. By compensating for the voltage drop in the loop circuit, this relationship may be made very close indeed.

GENERAL PRINCIPLES.

The general principles of the control exciter system will be appreciated by reference to the basic circuit (fig. 4). It will be seen that the exciter is provided with several field windings, the resultant effect of which determines its degree of excitation and consequently its output to the field of the main generator *G* which supplies the winder motor *M*. These fields fulfil the following functions. Field *A* is the control field and is energised by applying a pattern voltage. Field *E*, which opposes field *A*, is excited by the main generator *G*. The series field *B*, which includes a stabilising section, together with the stabilising shunt field *C*, serve to prevent hunting, while the field *D*, which is shown connected in series with forward and reverse rectifiers across the shunt in the generator-motor loop, is the current limit field.

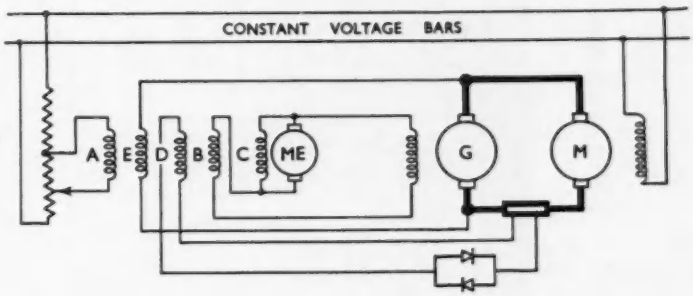


Fig. 4.—Basic circuit of the control exciter system with current limit feature.

Supposing the driver moves his lever from " stop " to the full " on " position, maximum pattern voltage is applied to winding *A* of the control exciter *ME*. This causes the control exciter to supply an initial forcing voltage to the field of the generator *G* so that its output voltage builds up quickly and the winder motor *M* is accelerated rapidly, i.e. the system ensures that the speed of the winder responds promptly to the movement of the driver's lever. As the voltage of the generator *G* increases, it applies an increasing excitation to the field *E* of the control exciter. Since this field opposes field *A*, these two fields are almost in balance, and their resultant excitation, together with that of the stabilising fields, is of the value needed to produce the requisite voltage in the generator *G* to run the winder motor at the desired speed as determined by the position of the driver's lever. Any change in the output voltage of the generator *G*, or in the pattern voltage, at once disturbs this state of balance and results in an immediate increase or decrease in the output of the control exciter and consequently of the generator so that balanced conditions are restored rapidly and accurately.

Similarly, movement of the driver's lever from full " on " to " off " reduces the excitation of field *A* to zero, leaving field *E* to provide a high over-excitation in the reverse direction. This in turn forces down the excitation of the main generator *G* so that the winder motor *M* regenerates and is quickly brought to rest.

The action of the stabilising fields is as follows. The series field *B* assists and the shunt field *C* opposes the control field *A*. When the generator field is changing rapidly, the current in the shunt field *C* rises far more quickly than that in the series field *B* owing to the damping effect of the inductance of the generator field. Thus the immediate resultant of these two fields opposes the control field and the rate of response is damped so that overshooting in the event of sudden changes in the pattern voltage is prevented. On the other hand, under steady running conditions, the resultant excitation produced by these two fields is such that the requisite output of the control exciter is maintained. With this arrangement the exciter is nearly self-exciting. This has the effect of increasing the accuracy of the system because any change in the input to the control field *A* will result in full output from the exciter.

The current limit field *D* safeguards the machines by limiting the current during acceleration or retardation to a maximum safe value. When the current circulating between the winder motor and generator exceeds a predetermined value, the volt drop across the shunt causes the appropriate rectifier circuit to be conducting (a metal disc rectifier requires a small but definite voltage in the forward direction before it can pass current). Thus any further increase in the current

in the motor-generator loop causes an appreciable current to flow in the field winding *D*. Since this field opposes the control field *A*, the output of the exciter is reduced, thereby limiting the voltage of the generator *G* to a value which ensures that only a safe maximum current will flow through the winder motor *M*. Similarly, when the plant is stopping and the motor begins to regenerate, the reverse current flowing from the motor to the generator is limited to the predetermined safe value.

Application of the Speed Control System.

In view of the size of the winder motor and the degree of amplification required, two control exciters (fig. 5) are installed and are connected in cascade.

pattern shunt field *A*1 and *A*2 of the pilot exciter *PE* and main exciter *ME* respectively.

The pilot exciter immediately energises the field *F*2 of the main exciter. At this stage the three fields, *A*1, *A*2 and *F*2, are unopposed so that a forcing voltage is built up across the main generator field *GF* and a voltage appears at the generator terminals. It should be noted that excitation of the exciter *PE* and *ME* is further assisted by the series fields *B*1 and *B*2.

So long as the mechanical brake of the winder is applied, the current flowing in the generator/motor loop circuit will be limited to a predetermined value (usually about twice full load) by the current limiting field *D*2, which is supplied through the rectifier *CLR*, as previously explained.

Fig. 5.—Control exciter set, 550 volt auxiliary control board and auxiliary transformer.

The complete system is shown in schematic form in fig. 6. The pilot exciter *PE* feeds the field system of the main control exciter *ME*, which in turn excites the main generator *G*. A constant voltage exciter *CVE* supplies the field *WMF* of the winder motor *WM*, the brake solenoid, and the operating coils of the various contactors and relays. With the winder motor at standstill and the driver's lever in the "off" position, the pattern potentiometer *PP* is de-energised, and the customary suicide connection through contactors *SC* is made for the generator field. Movement of the driver's lever first closes the appropriate direction contactors to connect the potentiometer *PP* to the constant voltage supply in the appropriate sense for the required direction of rotation, and removes the suicide connection so that the main generator field is connected across the armature of the control exciter *ME*. The selected voltage, as determined by the position of the driver's lever, is now applied to the

On releasing the brake, the motor *WM* will begin to accelerate and generate a back e.m.f., but the combined effect of the control exciter fields *A*2, *F*2 and *D*2 is such that the excitation of the generator *G*, and consequently its voltage, is automatically increased at the necessary rate to maintain the required current in the generator/motor loop circuit.

As the speed of the motor rises and the generator voltage increases, the reset fields *E*1 and *E*2 of the control exciter set are energised. The voltage applied to these fields is made proportional to the back e.m.f. of the motor by means of a resistance network so that it reflects very closely the speed of the motor. The fields *A*1 and *A*2 are now opposed by *E*1 and *E*2, and acceleration at constant torque continues until the motor reaches the desired speed. At this speed, the fields *A*1 and *A*2 are very nearly balanced by *E*1 and *E*2, a very small difference sufficing to maintain the requisite excitation and voltage of the generator *G*.

It should be appreciated that throughout the acceleration period, the current limit field *D2* opposes the resultant field produced by the windings *A2*, *E2* and *F2* so that the current flowing through the motor is limited to the desired value.

Furthermore, the fields *A2*, *E2* and *F2* are so proportioned in relation to the characteristics of the pilot exciter *PE* that the main exciter *ME* gives maximum output whenever the speed of the motor *WM* differs from the required speed by more than 10 per cent. This slight "looseness" facilitates manoeuvring at low speeds by allowing a measure of torque control.

ferred to a voltage relay connected across the winder motor *WM* so that the suicide connection is held off until the voltage across the winder motor *WM* has fallen to a very low value. The occurence of an emergency trip also results in the automatic adjustment of the effect of the current limit field *D* to avoid excessive regenerative torques.

In the event of any failure to reduce speed at the point at which deceleration should begin, returning cam gear comes into operation and automatically controls the rate of deceleration. The usual facilities for overriding the action of the cam are provided.

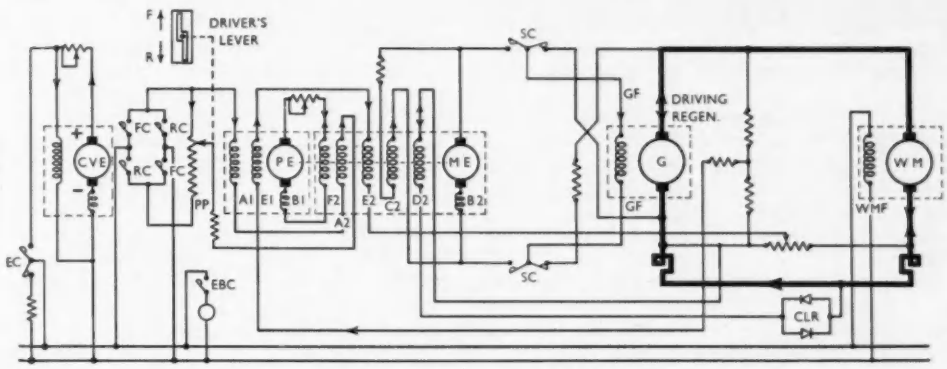


Fig. 6.—Control exciter system for the 3,700 h.p. winder.

A similar sequence of events takes place when the winder is running at a steady speed and the driver's lever is returned to stop. Thus at all times the winder speed is made to follow the position of the driver's lever very accurately, being subject only to temporary divergence due to the current limit feature.

The safety circuit and protective features follow standard practice and do not call for any special comment. Following any emergency trips, the tripping of the emergency brake contactor *EBC* removes any excitation of the pattern fields *A1* and *A2* so that a zero pattern speed is given irrespective of the position of the driver's lever. At the same time the suicide connection of the main generator field *GF* is trans-

It is deserving of note that since the winder was commissioned its performance has fully substantiated the claims made for this system of control which, it will be appreciated, is readily adaptable to automatic winders and is particularly suitable for friction winders where the avoidance of rope slip is of paramount importance.

ACKNOWLEDGMENT.

Acknowledgment is made to the National Coal Board for permission to publish this information and for the facilities granted to obtain photographs of the installation.

Voice-operated Switching for Loudspeaking Telephone

COMMUNICATION between offices in a building through an internal telephone exchange is an essential business facility. When loudspeaking telephones are used for this purpose, the parties to a conversation are free to make notes, consult files, or move about the room while speaking, but the degree of freedom is limited if each person has to operate a talk/listen key at the end of every transmission.

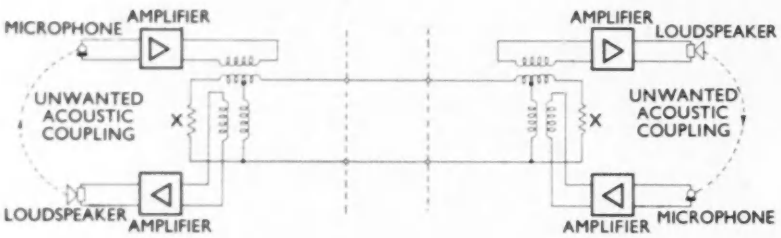


Fig. 1.—Sources of feedback in typical two-wire loudspeaking telephone circuit.

The purpose of the talk/listen switching is to prevent acoustic feedback from causing a howl in the loudspeakers. Fig. 1, showing the interconnection of two loudspeaking telephones over the normal two-wire circuit through a private automatic exchange, illustrates the conditions in which feedback may occur. Unless the impedance of the balance *X* matches the line and termination for all conditions and frequencies, some of the microphone amplifier output will appear in the local loudspeaker, and if this is fed back to the adjacent microphone it will give rise to a closed feedback loop, and cause the loudspeaker to howl. Matching the balance to all conditions of line impedance is difficult in practice, and would have to cater for the extreme conditions presented to the line at the distant end, namely, a telephone being rung and a telephone answered. Even with an ideal balance any acoustic coupling between microphone and loudspeaker at both ends would be amplified and result in howl-round. For these reasons switching is necessary to attenuate the microphone and loudspeaker sections of the circuit. Manual operation has the drawback mentioned already, and the G.E.C. has therefore introduced a new loudspeaking telephone in which the switching is voice-operated.

The equipment consists of the loudspeaking telephone itself (fig. 2) with the loudspeaker and microphone housed in a desk-mounting cabinet, and a separate wall-mounting amplifier unit (fig. 5) comprising transmit and receive amplifiers and a differential d.c. amplifier which controls the voice-operated switches in the two speech paths.

A conventional handset is mounted on the side of the cabinet for use if it is desirable that incoming speech should not be overheard by other people present in the room. The loudspeaker is automatically switched out of circuit when the handset is lifted from its rest. The user may also prevent a distant caller from hearing a local conversation by operating a key to switch the microphone out of circuit.

Fig. 2.—Loudspeaking telephone fitted with direct-access calling keys.

In addition to the usual automatic dialling, a system of direct-access calling is provided which enables up to twenty of the extensions most frequently required to be instantly obtained by operating the appropriate key.

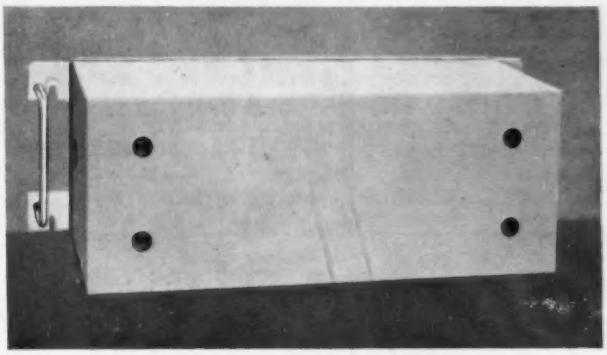


Fig. 5.—Amplifier unit of loudspeaking telephone.

AMPLIFIER CIRCUIT.

The amplifier circuit, shown in block form in fig. 3, is arranged so that when the transmit switch is open the receive switch is closed, and vice versa. When the circuit is in the quiescent state, the send switch is slightly biased so that when either party speaks, speedier operation of the distant receive switch is obtained.

SPEECH PATH—TRANSMIT DIRECTION.

A simplified diagram of the speech paths is shown in fig. 4. The speech signals from the microphone are fed to the input grid of valve *V*1 through a transformer *TR*1. The output of this first valve is resistance-capacitance coupled to the input of the second valve *V*2.

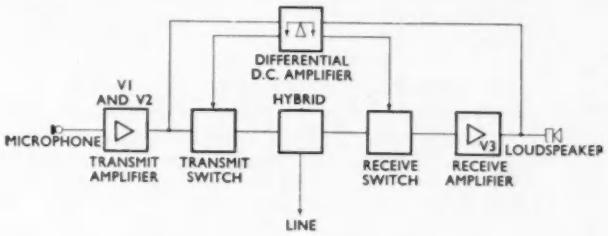


Fig. 3.—Block diagram of amplifier.

The anode circuit of *V*2 contains two transformers, *TR*2 and *TR*3, connected in parallel. *TR*3 forms the output transformer, which matches the amplifier to the external line circuit, and is also part of the hybrid circuit. The stability of the amplifier is increased by negative feedback from *TR*2 to the cathode of *V*1. The tertiary winding on *TR*2 provides the voltages which operate one side of the differential switch.

SPEECH PATH—RECEIVE DIRECTION.

The incoming signals are applied to the grid of *V*3 through transformer *TR*4. The output of *V*3 is coupled, again through a transformer, to the loudspeaker. A tertiary winding in this transformer, *TR*5, is connected to the switching circuit. The tertiary winding on the transformer *TR*4 allows for increased volume from the loudspeaker under the control of a manually-operated key on the desk unit. Where increased volume is required permanently on any direct-access call, strapping is applied to the appropriate terminals.

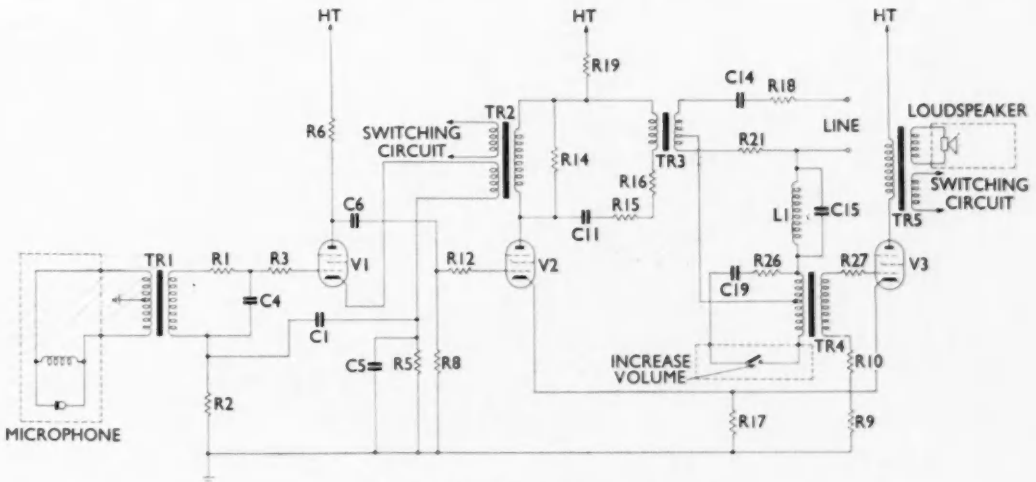


Fig. 4.—Simplified circuit showing speech paths.

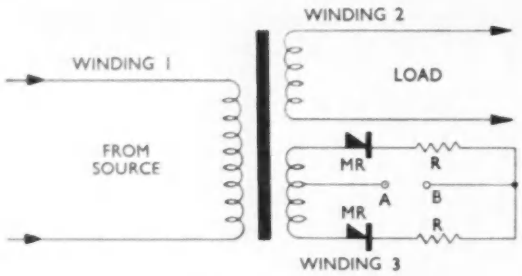


Fig. 6.—Basic circuit of electrical switch.

The choke and capacitor $L1$ and $C15$ reject any 100 c/s mains ripple that may be on the line.

VOICE-SWITCHING CIRCUIT.

The following features have been incorporated in the voice-switching circuit :

The switch, which is operated by the first spoken word, is sufficiently fast to reduce any clipping of the speech to an almost undetectable amount.

A fade-in and a fade-out circuit have been incorporated to guard against unpleasant noises in the loudspeaker on a sudden changeover.

A short delay to the switching at the completion of a sound provides a hangover time between words to preserve natural continuity of speech.

The differential-switching circuit gives access to the speaker from either end, and provides a break-in feature enabling a loud signal from one end to break in to a weaker one from the other. This allows a speaker to operate the channel against room noise, which may tend to hold the return channel against him.

CHANGEOVER SWITCH.

The switching is performed electrically by varying the conductivity of shunt elements connected in either speech path. There are two switches, one in each transmission path. The switches are controlled by the speech voltages and are operated differentially.

The basic circuit of the switch is shown in fig. 6. When a potential difference exists between the points A and B, the rectifiers MR are conducting or non-conducting according to the polarity. When the rectifiers are conducting, the impedance presented to winding 3 of the transformer is so low that it virtually short-circuits the load impedance, and the output signal is greatly attenuated. Reversal of the polarity of terminals A and B will increase the impedance of the rectifiers so that winding 3 is virtually open-circuit, and there is negligible attenuation between the source and load.

The points A and B are the balance points of a bridge formed by the two halves of winding 3, rectifiers MR, and resistors R. When the two rectifiers are matched there is negligible a.c. potential across A and B. Both the transmit and the receive switches can therefore be operated from the same d.c. source, without risk of signals passing from one path to the other.

D.C. AMPLIFIER.

The rectifier switches described in the last paragraph are operated by a differential d.c. amplifier (fig. 7). The output of the amplifier, across A and B, is normally zero, and can be set accurately by the potentiometer $RV1$.

SWITCHING OPERATION—TRANSMIT.

When the microphone is transmitting, valve $V2$ is conducting and part of its output is fed via transformer $TR2$ to the rectifier $MR1$ and its associated

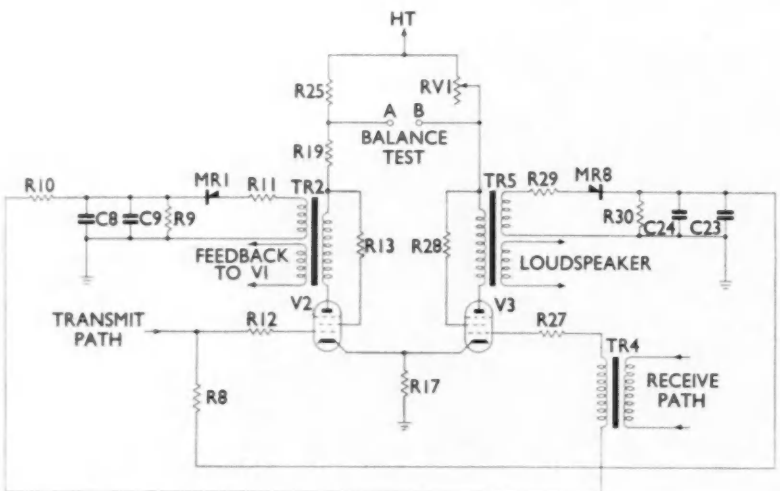


Fig. 7.—Circuit of differential d.c. amplifier.

resistors and capacitors. The rectified output is fed to the input of *V*3, the resulting increase in grid potential causing the anode current of *V*3 to increase. With the increase in anode current the potential of *B* becomes negative with respect to *A*. The increase in current through *V*3 causes the current through resistor *R*17 to increase, and hence the potential of the cathode of *V*2 to become more positive with respect to the grid. Thus the anode current of *V*2 is reduced and the potential of *A* becomes more positive with respect to *B*.

In the second part of the switching circuit (fig. 8) the points *A* and *B* are the same as those shown in fig. 7. A potential difference between these points in the direction described in the previous paragraph is such that the rectifiers *MR*5 and *MR*6 will have low resistance to the flow of current. The construction of the transformer is such that under these conditions it is short-circuited, thus suppressing the loudspeaker circuit. The louder the user speaks, the greater will be the voltage unbalance and the greater the attenuation produced.

Switching Operation—Receive.

Since the circuit of the differential amplifier is symmetrical, the operation in the receive direction is similar to that for the transmit direction. In this instance, however, the polarity of the points *A* and *B* is reversed, and rectifiers *MR*2 and *MR*3 present the low-resistance path to render transformer *TR*3 ineffective and suppress any sound picked up by the microphone. Again, the louder the wanted signal the greater will be the suppression of other signals.

Breaking In.

The switching control described in the last paragraph is gradual. The fact that a higher switching voltage is produced by louder speech is used to provide a break-in facility.

When a speech signal is being received, a winding of *TR*3 attenuates the outgoing speech circuit. However, *V*2 is not suppressed, and if a listener speaks louder than usual an out-of-balance voltage will

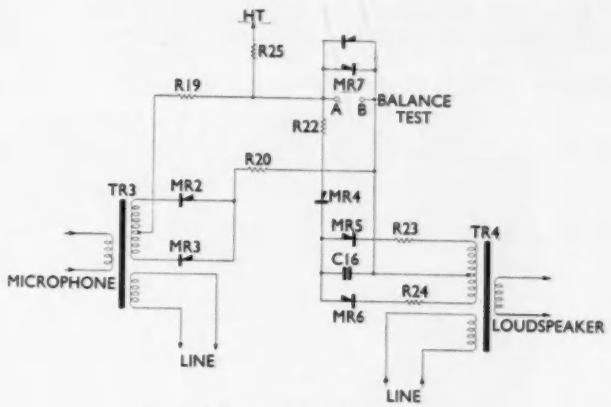


Fig. 8.—Voice-operated switching circuit.

be produced between *A* and *B* large enough to neutralise, and then reverse, the out-of-balance condition already existing due to the incoming signal. Similarly the switch position is reversed at the distant end.

Research in Nuclear Power

AS a result both of the Scottish nuclear power station contract now in hand, and the plans announced by the Government in March for trebling the original output target of this country's nuclear power programme, the work of the G.E.C.—Simon-Carves Atomic Energy Group has increased in tempo, and has been accompanied by a great expansion of the number of staff employed and the facilities available. There are now more than 300 highly specialised personnel wholly engaged on nuclear power development at the Group's headquarters at the Fraser & Chalmers Engineering Works, Erith ; the cost of this project to the Company at present exceeds £½ million per annum, and this figure will undoubtedly be increased in the future.

The Group's laboratories and offices at Erith now occupy a total area of 33,000 sq. ft. contained within a single building, and preparations are well advanced for further large extensions. The main heat laboratory is comprehensively equipped with heat transfer research apparatus and also contains a number of reactor prototype units which are undergoing development trials. A second materials research laboratory has recently been built and equipped, and the design office of the Group has now been completed to accommodate up to 70 draughtsmen in the most modern conditions.

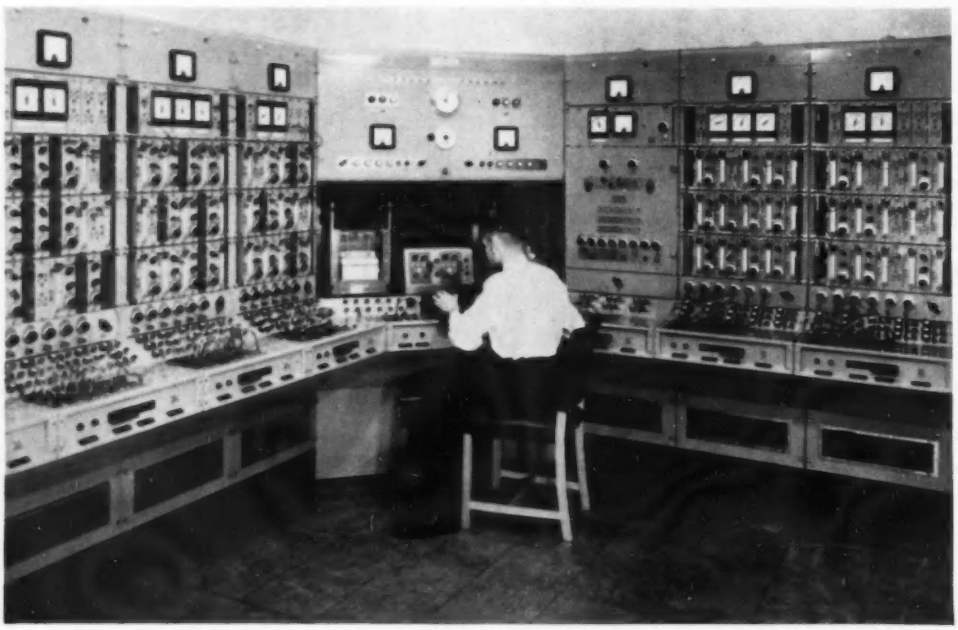


Fig. 1.—Electronic analogue computer.

ANALOGUE COMPUTER.

One of the most important items of equipment installed during 1956 was an electronic analogue computer which can simulate the performance of a complete nuclear power station. The computer (fig. 1) is the largest and most advanced of its type in this country to be used exclusively for nuclear power studies. It enables the behaviour of any unit or group of units in the power station to be predicted accurately and quickly without the need for long and laborious calculations.

The main initial uses of the computer have been in the study of transient phenomena occurring in a nuclear power station following disturbances, such as fault conditions, and in the analysis of automatic control systems.

The flexibility of the computer was carefully considered during the design stages, with the result that it will be equally useful in the investigation of more advanced forms of reactor than the gas-cooled, graphite-moderated type now under development.

An unique and most important feature of the new computer is that it has been designed to operate either as one large machine or as two completely independent smaller machines. It is thus possible to examine simultaneously two entirely separate problems, with the advantage of considerable time-saving where neither problem requires the use of the complete machine.

In many of the problems encountered the time scale is likely to vary from a fraction of a second to several hours. The computer normally operates in real time, and the performance of any section of the power station can be examined from the traces of two continuous high-speed pen recorders which allow four variables to be recorded simultaneously. Alternative indication of each section is provided by a cathode ray oscilloscope.

An additional advantage of real time working is that actual units of control systems can be coupled into the simulator circuit and their behaviour analysed. For longer-term problems, such as the effects of xenon poisoning of the fuel, the rate of working can be accelerated.

The computer comprises a total of eight cabinets, arranged in " L " formation with the control cabinet at the junction. One special cabinet is permanently connected to simulate the nuclear reactor itself, and the remaining six are identical general purpose cabinets which can be set up to simulate the performance of heat exchangers, control rods, blowers, turbo-alternators or other components of the power station plant. This arrangement allows the equipment to be used with a high degree of flexibility, and will enable a wide variety of problems to be studied.

Fig. 2.—Experiments on the heat transfer properties of fuel cans.

Provision is made for the incorporation of 100 drift-connected amplifiers and 20 servo-multiplier units. At present 84 amplifiers are available, any one of which can be used as a summing amplifier, integrator, or servo-amplifier. Two transit time units are provided for the simulation of time delays, the output signal of each unit being the input signal delayed in time.

The simulator was manufactured by the Nuclear Division of Elliott Bros. Ltd., who also collaborated with the G.E.C. in the design of the machine.

HEAT TRANSFER RESEARCH.

Fuel Cans.

In the present design of nuclear reactor, heat is extracted from the natural uranium fuel by carbon dioxide gas circulated under pressure by blowers. The fuel rods are contained within a magnesium alloy can which must have some form of extended or finned surface to assist in the extraction of heat. The amount of heat which can be extracted from a fuel can is one of the controlling factors in reactor design, and the investigation of heat transfer characteristics is an important part of the experimental work undertaken at Erith.

In the main heat transfer apparatus (fig. 2) the measurement of heat transfer coefficients and friction factors is carried out under conditions of temperature and pressure resembling those in a reactor. The fissile fuel is replaced by a stainless steel heating element inside the fuel can, the heater power being supplied by two d.c. generators. The can is supported within a copper tube which is lagged to prevent heat losses. Carbon dioxide from Cardice generators is circulated under pressure throughout the system by a steam turbine-driven blower; provision is made for supplying the gas with extra heat and also for making-up the losses of gas that occur during circulation.

During tests, measurements are made of gas and fuel can temperatures and of gas flows and pressure drops so that a heat balance can be obtained.

For other experimental work there is also a heat transfer rig in which experiments are carried out in air at atmospheric pressure instead of under pressurised carbon dioxide. This equipment is basically similar to the CO_2 rig but is very much simpler and quicker to operate. In this case air is drawn over the cans by a blower which is driven by a constant speed motor through a fluid drive. The apparatus provides valuable data on the maximum heat output that can be obtained from a given design of fuel can at a particular temperature.

Apart from the problem of extracting heat from the fuel cans, there is the question of heat transfer within the can itself, i.e. from the centre of the fuel rod, where the heat is generated, to the outside of the fuel, and also from the surface of the fuel to the walls of the can. The effects of surface roughness on the inside of the can and of oxide films on the uranium are additional factors influencing the effectiveness of heat transfer.

These and other problems are all receiving intensive study from the point of view of the present design and, no less important, with an eye to future reactors of improved performance.

Steam-raising Plant.

On leaving the reactor, the hot gas is led away to heat exchangers where it gives up its heat to water and the steam so generated is used to drive the turbo-alternators.

Because of the relatively low temperature difference compared with fuel-fired plant of the same output, great attention has been paid to the problem of obtaining the most compact arrangement of heat exchange surface in order to keep to a minimum the size of the pressurised vessel required.

The solution adopted is to use large numbers of small diameter steel tubes with an extended surface in the form of fins. The combined heat exchangers for one nuclear power station might contain up to 200 miles of tubing. The use of extended surfaces in such large plant and under such conditions is unusual and has entailed a major development programme on the metallurgical and manufacturing aspects as well as an investigation into heat transfer and pressure drop.

Equipment constructed for the experimental work, shown in fig. 3, has permitted the rapid testing of numerous alternative designs of extended surface tubes under varying conditions of temperature and pressure drop.

Prototype Testing.

It is essential that equipment which is of vital importance to the successful operation of the reactor

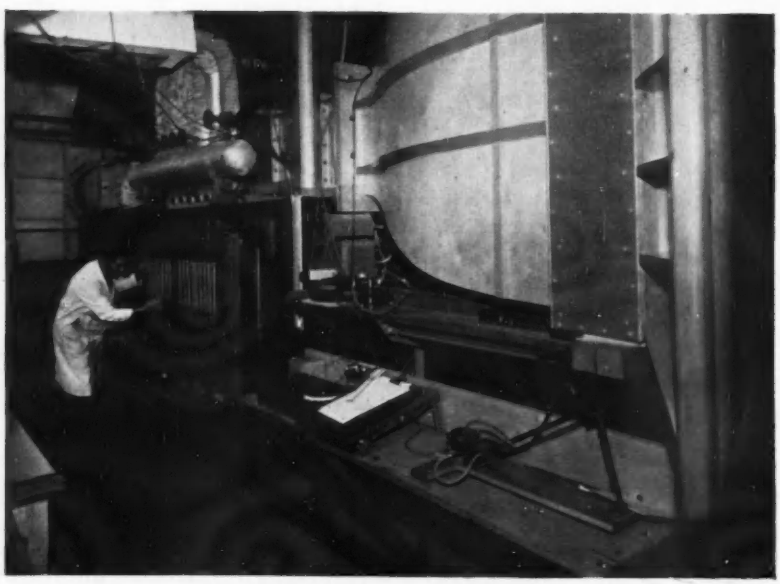


Fig. 3.—Investigating the heat transfer characteristics of heat exchanger tubes.

should be thoroughly tested under reactor operating conditions before it is installed. A number of prototype units are therefore undergoing tests in the Erith laboratories. These units include sections of the charge and discharge equipment, which will be capable of operation while the reactor is running, control rod operating mechanisms, gas selection valves, special gas seals for carbon dioxide blowers, mechanical and electrical drive units operating in hot carbon dioxide, and bearings which will have to run in hot gas without conventional lubrication.

Tests are also being carried out on pneumatic motors, driven from a compressed air supply, running in a furnace under carbon dioxide pressure and at temperatures up to 200 deg. C.

MATERIALS RESEARCH.

The functions of the two materials research laboratories at Erith are to assess the performance of materials for use in the present design of reactor and to carry out research into new and modified materials for future designs. The laboratories are specially and comprehensively equipped to deal with the type of problems presented in nuclear power station design.

Corrosion and Oxidation of Metals.

The carbon dioxide coolant gas circulated under pressure through the reactors and heat exchangers will contain small amounts of carbon monoxide, produced by interaction with the graphite moderator, and of water vapour. A considerable amount of experimental work has therefore had to be carried out to determine the oxidation and corrosion resistances of materials in the reactor circuit to these gases.

The principal interest so far has been in magnesium alloys used for the fuel element cans and in various steels used in the construction of the reactor pressure vessels, heat exchanger shells, gas ducting and other components.

A special thermobalance has been designed and constructed for the rapid measurement of magnesium oxidation rates in carbon dioxide. It consists of an electrically heated pressure vessel containing a spiral quartz spring supporting the specimen. The specimen is heated in an atmosphere of carbon dioxide under pressure, and as oxidation takes place, weight changes are reflected in the vertical movement of the quartz spring.

The reactor pressure vessels and heat exchanger shells are both of welded steel construction and the selection of suitable steels needs careful consideration. The pressure vessels will be fabricated on site and the essential requirements of the steel are resistance to creep at the operating temperature, resistance to failure by brittle fracture, and weldability.

Each reactor pressure shell will weigh several hundred tons and will be subjected to a combination of pressure and temperature never before attained in a vessel of this size.

For corrosion tests on steels and other alloys, a battery of 23 G.E.C. vertical heat treatment furnaces has been installed in the two laboratories. Each furnace is fitted with a removable pressure-tight stainless steel autoclave in which specimens are placed. Tests have been carried out in carbon dioxide/carbon monoxide mixtures of varying compositions, with and without additions of water vapour, and over a range of gas pressures.

Creep Tests.

The cooling fins on the fuel element cans are subjected to bending stresses caused by the high-pressure coolant gas flowing over them. The fins may therefore creep during operation, and a test rig has been devised to examine this effect.

In addition, a battery of special-purpose equipments, designed in the Erith laboratories, has recently been installed to provide preliminary creep and stress-rupture data. In this type of apparatus, experiments can be performed on metals and alloys in gaseous atmospheres at pressures up to 200 p.s.i.g. at 500 deg. C. Work initially has again been on magnesium alloys in carbon-dioxide atmospheres, but the equipment can readily be converted for future work to deal with other materials and other gases.

High-frequency Furnace.

One of the most useful and versatile pieces of equipment for metallurgical research is a G.E.C. 25 kW high-frequency furnace. The furnace can be used for the induction melting of small amounts of experimental metals and alloys, including those with very high melting points, and for work on powder metallurgy and brazing.

Welding.

The development of welding techniques for magnesium alloys and other materials such as stainless steel is an important part of the design programme. A 300-amp argon arc welding set is therefore installed in one of the metallurgical laboratories, and can be operated with either manual or automatic control.

WEMBLEY RESEARCH LABORATORIES.

The G.E.C. Research Laboratories at Wembley have undertaken a number of programmes of investigation complementary to the research being carried out at Erith.

The Carbon group has studied the physico-chemical characteristics of the reactions which may occur between the graphite core and the coolant gas (carbon dioxide), and is developing methods for preventing the mass transfer of carbon within the reactor circuit.

The effects of stress and moisture content on the scaling rate of steels in carbon dioxide has been investigated by the Metallurgy group, which is also examining the compatibility of the magnesium canning alloy with other reactor materials.

Another group at Wembley has worked on a number of heat transfer problems relating to the present reactor design, and is concentrating now on long-term research into improved channel arrangements to give higher heat ratings per channel without excessively increased gas pumping power.

Hot Cathode Xenon Rectifiers

By K. G. COOK, B.Sc.(Eng.),
Research Laboratories.

Xenon filled rectifier valves have certain advantages over mercury vapour valves, particularly where quick warm-up and ability to operate over a wide range of ambient temperature are essential.

With the introduction of improved designs, the lives of xenon valves are as good as those of the mercury filled types and it is anticipated that xenon filling will eventually be preferred in the majority of applications.

IN a power rectifying circuit which is used for the conversion of alternating current to direct current, the rectifier valves should have a low resistance to the passage of current in the forward direction, but pass little or no current in the reverse direction. There are many different types of valve which can be used, some of the most important being mercury pool rectifiers, selenium and germanium semiconductor rectifiers, vacuum valve rectifiers and hot cathode gas-filled rectifiers of which the xenon valve is a typical example. Each of these rectifiers has its own particular field of application in which for one reason or another it has advantages over the other types.

HOT CATHODE GAS-FILLED VALVES.

The hot cathode gas-filled rectifier is particularly suited to the high voltage medium current field. Peak inverse voltages between 5 and 20 kV and mean currents between 0·25 and 5 amp are typical for these valves. Depending upon the circuit employed, these ratings enable d.c. power packs to be constructed giving output voltages from 2 to 20 kV at mean currents between 0·5 and 15 amp. Power packs of this type are required as high tension supplies for the vacuum oscillator valves in radio and television transmitters and in high frequency induction heaters.

MERCURY VAPOUR AND XENON RECTIFIERS.

There are various gas fillings which can be used in a gas-filled rectifier, those most commonly chosen being mercury vapour and xenon. The most important properties of valves using these two gases are given in Table 1.

TABLE 1.

	Mercury Vapour	Xenon
Volt drop	10 volts	10 volts
Ambient temperature	+10° C. to +50° C.	−55° C. to +70° C.
Warm-up time	10-30 minutes	30 seconds
Storage properties	May deteriorate on shelf	No deterioration
Life (at present)	5,000-10,000 hours	2,000-10,000 hours

There is little to choose between mercury and xenon in rectification efficiency or in the maximum inverse voltages and maximum mean currents which can be achieved with the two types of filling.

Mercury valves are quite suitable for use in temperate countries, but for operation in very hot or very cold climates xenon is preferred. Xenon valves also have the advantage of a short warm-up time. Mercury valves tend to deteriorate on shelf due to attack of the cathode coating by mercury, whereas xenon valves are unaffected even by very long storage periods.

One advantageous feature of mercury filling is that the vapour does not disappear during the operation of the valve. With xenon, on the other hand, the life of the rectifier is eventually limited by the disappearance, or " clean-up ", of the gas filling.

Before about 1950 mercury valves were the most widely used since they were easily manufactured and had satisfactory lives. More recently xenon valves have taken the lead, particularly where a short warm-up time and an ability to operate over a wide range of ambient temperature have been essential factors in the operation of the rectifier. With the introduction of improved designs, the effects of the clean-up of xenon have been much reduced and lives of 10,000 hours are now becoming increasingly common.

BASIC PRINCIPLES OF THE HOT CATHODE GAS-FILLED RECTIFIER.

IONISATION.

A gas-filled rectifier valve has three main elements : a hot emissive cathode, an anode and a gas filling. The cathode consists of a nickel strip or cylinder coated with a mixture of barium and strontium oxides. When heated to about 800 deg. C. the cathode emits electrons copiously. If a positive voltage is applied to the anode, the electrons are accelerated across the valve and a current flows in the external circuit.

If no gas is present, as in a vacuum valve rectifier, a negative space charge of electrons forms outside the cathode and a relatively high anode voltage is needed to draw the available cathode emission across the valve.

If a gas such as xenon is added, some of the electrons in their passage from cathode to anode collide with

neutral xenon atoms. In the collisions the xenon atoms may become ionised, i.e. the outermost xenon electrons become detached, leaving the xenon atoms positively charged. These positive ions are attracted back towards the cathode where they neutralise the negative space charge. The whole available cathode emission can then be drawn across the valve with only a very small anode voltage.

The electrons leaving the cathode will not cause ionisation until they have a certain minimum energy. They gain this energy by accelerating through a voltage defined by the ionisation potential of the gas. Most hot cathode gas-filled rectifiers therefore have a volt drop between cathode and anode approximately equal to the ionisation potential of the gas filling. In the case of xenon this drop is about ten volts and is substantially independent of the anode current.

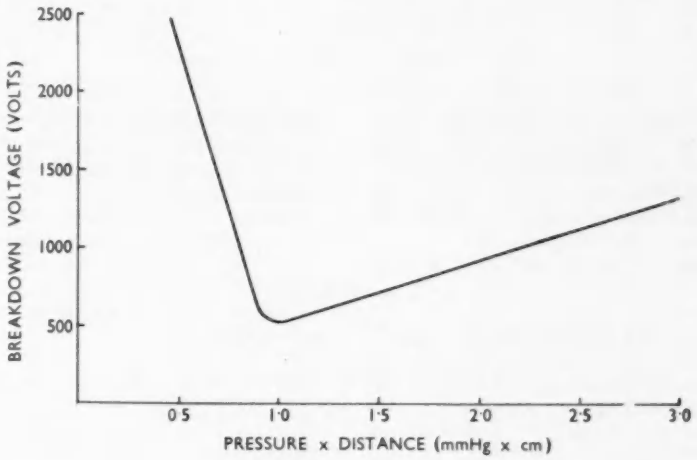


Fig. 1.—Paschen breakdown curve for xenon.

BREAKDOWN.

During the reverse half cycle of rectification, when a negative voltage is applied to the anode, the valve should ideally pass no current at all. The highest reverse voltage which the valve will withstand without passing appreciable current is called the peak inverse voltage. Reverse breakdown in a xenon rectifier is governed by Paschen's law, which states that the breakdown voltage between two electrodes in a gas is a function of the product of the pressure of the gas filling and the distance between the electrodes. The negative electrode is assumed to be non-emissive.

In the case of a xenon rectifier the anode and cathode form the two electrodes, the anode being negative during the reverse cycle of rectification. The anode is of course non-emissive, so the Paschen relation can be applied.

The form of the Paschen curve for a xenon rectifier is shown in fig. 1. For various reasons it is only practicable to operate at pressures and spacings on the left-hand side of the potential minimum of the curve. To achieve a high breakdown voltage, it can be seen that the pressure should be kept as low as possible, and the spacing between anode and cathode should be made as small as possible.

EXCITATION.

When an electron collides with a xenon atom, it sometimes causes excitation rather than ionisation. In this condition, the outermost electron of the xenon atom is not detached completely, but merely moves into a more energetic or excited orbit. This electron will subsequently fall back into its normal orbit and at the same time an equivalent amount of energy will be radiated from the atom in the form of light. It is this light which gives the characteristic colour of the gas discharge, the wavelength radiated depending upon the particular gas atom involved and the level of excitation. In xenon rectifiers the light is purple initially, changing to red as the gas in the valve is cleaned up.

DESIGN OF A TYPICAL XENON RECTIFIER.

Fig. 2 shows a section of a modern GXU3 xenon rectifier. The oxide coated cathode *A* is of the directly heated type. The heater current for the cathode is supplied through leads *B*. *C* is an iron anode disc which is supported by a tungsten rod *D*. *E* is a baffle which screens the anode from the cathode. The baffle prevents barium, which is continuously evaporated from the cathode, from settling on the anode. If the anode were to become coated in this way, it would emit electrons when it became hot in operation and the valve would break down during the negative half cycle of rectification.

The screening *F* which surrounds the anode is a most important feature of the design. This screening is at cathode potential and as a result the lines of force between the anode and the cathode assembly are

everywhere as short as possible ; there are no " long paths ". Referring to Paschen's law, it is obvious that since the effective distance between anode and cathode potentials is small, then the reverse breakdown voltage is high. Equally, for a given peak inverse voltage, if the path is short then the maximum permissible filling pressure is high. This feature, which is usually called a " boxed-in anode ", was first introduced into high voltage xenon valves by the M.O. Valve Company.

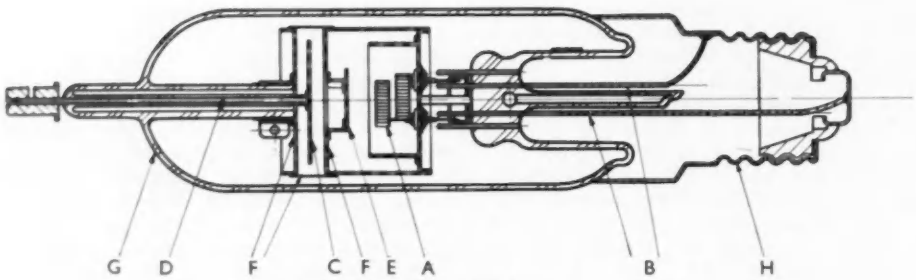


Fig. 2.—Section through GXU3 xenon rectifier.

The whole electrode structure is enclosed in a glass envelope *G* and a suitable cap *H* is provided for inserting the valve in the rectifying circuit.

The general appearance of the valve is shown in fig. 3.

GAS CLEAN UP IN XENON RECTIFIERS.

The factor which most affects the performance of xenon rectifiers is the gradual disappearance of gas during life, usually referred to as " clean-up ". The valve is filled during manufacture to a pressure of about 0·1 mm.Hg. of xenon. In operation the gas cleans up until finally, after a life of several thousand hours, when the pressure has fallen to about 0·01 mm.Hg., the valve fails to conduct.

The gas appears to be adsorbed by the electrodes of the valve and by the glass of the envelope. It is extremely difficult to prevent clean-up from occurring and the most satisfactory way of achieving a long life is to design a valve which can be filled to a high pressure in manufacture. This emphasises the importance of the " boxed-in " structure.

It has been observed that the rate of gas clean-up is very much reduced if the valve is run below its maximum peak inverse voltage. Typically, if a valve is run at half voltage, the life may be trebled and it is not uncommon to achieve 15,000-hour lives with xenon rectifiers run at reduced voltage. The current loading does not appear to have a major effect upon the clean-up. High operating frequencies cause an increase in the rate of gas clean-up and it is usual to limit a xenon rectifier to a maximum operating frequency of 150 cycles.

PRODUCTION TYPES OF RECTIFIER.

Table 2 gives the most important characteristics of the xenon rectifiers which are at present in production.

Depending upon the type of rectifying circuit employed, various d.c. outputs can be achieved when using these valves. Table 3 gives the maximum outputs which can be obtained in two particular circuits, the single-phase full wave circuit

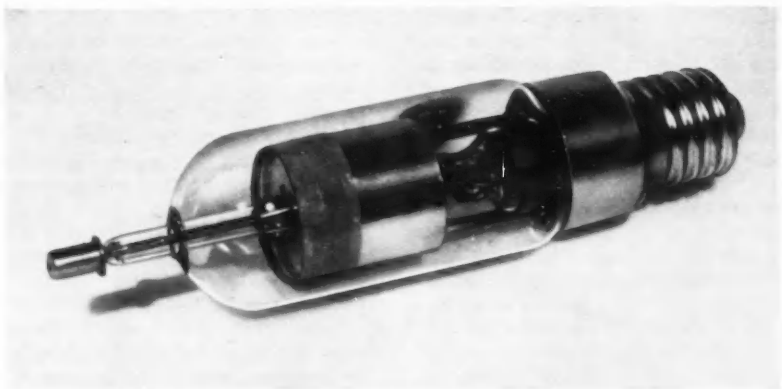


Fig. 3.—The GXU3 xenon rectifier, 13 kV P.I.V., 1·5 amp mean current.

as shown in fig. 4 and the three-phase full wave circuit as shown in fig. 5.

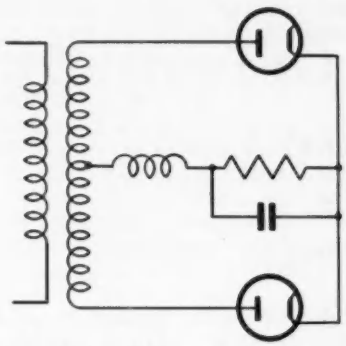


Fig. 4.—Single-phase full wave circuit using two valves.

FUTURE DEVELOPMENTS.

The present trends of development in xenon rectifiers are towards higher powers, higher peak inverse operating voltages and longer lives. New types of rectifier have been designed for operation at 15 kV peak inverse voltage. In order to achieve this performance, and also to permit the use of the higher gas filling pressure which will extend the life of the rectifier, novel designs have been evolved which reduce to a minimum the effective Paschen breakdown path between the anode and the cathode. Now that the life of xenon rectifiers has been increased into the 5,000 to 10,000 hours range, mercury vapour filling ceases to have any outstanding advantages. It appears likely that xenon will be preferred as the gas filling for most types of hot cathode gas-filled rectifier in the near future.

TABLE 3.

No.	d.c. output in single-phase full wave	d.c. output in three-phase full wave
GXU1	3 kV 500 mA	9 kV 750 mA
GXU2	3 kV 2·5 A	9 kV 3·75 A
GXU3	4 kV 2·5A or 3 kV 3 A	12 kV 3·75 A or 9 kV 4·5 A
GXU4	4 kV 2·5 A	12 kV 3·75 A
GXU5	3 kV 6 A or 2·2 kV 8 A	9 kV 9 A or 6·6 kV 12 A

TABLE 2.

No.	Length	Dia.	Fil. Volts	Fil. Current	Max. Mean Current	Max. PiV
GXU1	6 in.	2 in.	2·5 volts	5 amp	250 mA	10 kV
GXU2	8 in.	2½ in.	5 volts	7 amp	1·25 amp	10 kV
GXU3	10½ in.	2½ in.	4 volts	11 amp	1·5 amp	13 kV
GXU4	10½ in.	2½ in.	4 volts	7 amp	1·25 amp	13 kV
GXU5	12 in.	3¾ in.	2·5 volts	30 amp	4 amp	10 kV

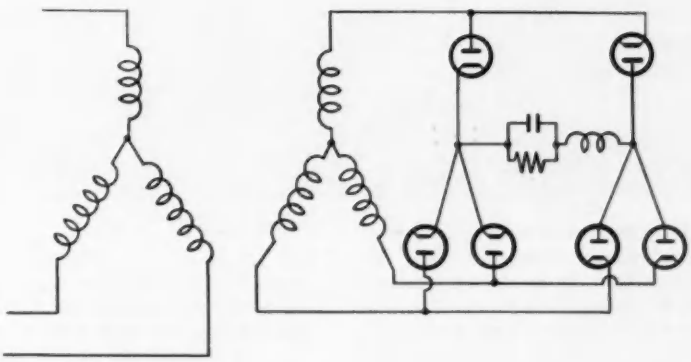


Fig. 5.—Three-phase full wave circuit using six valves.

Pump Drives for New Graving Dock at Singapore

By O. B. WOLSTENHOLME,
Manager, Engineering Department, The General Electric Co. (Malaya) Ltd.

INCREASING demand on graving dock facilities at Singapore, hitherto provided by the King's Dock, has made it necessary to build a new dock of this type. The new dock (fig. 1), known as the Queen's Dock, is situated at the western entrance to Keppel Harbour, as shown in fig. 2, and was brought into service last year. It measures 605 ft. long from the inner sill, is 85 ft. wide at the entrance, and has a depth at low water of 17 ft. 6 in. The dock gate is of the single-leaf type, which is opened by being lowered through the water to lie horizontally so that ships can pass over it.

Alternating current motors totalling over 1,000 h.p. have been supplied by the G.E.C. for driving the pumping equipment in the dock, which has a total capacity of 1·7 million cu. ft., or 11 million gallons. The two main de-watering pumps are together capable of emptying the dock in 2¼ hours.

High-voltage and low-voltage switchgear, control boards, and the main control desk have also been

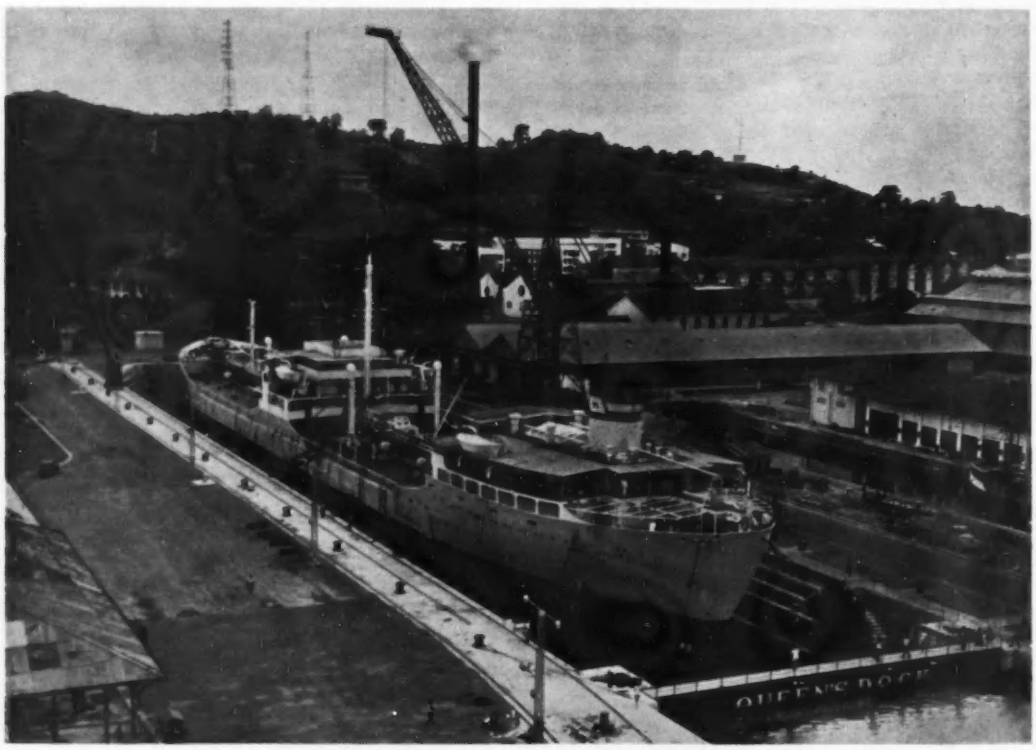


Fig. 1.—The new Queen's Dock at Singapore.

supplied under contract to Gwynnes Pumps Ltd., the main contractor to the Crown Agents for Overseas Governments and Administrations for the whole of the pumping equipment. The pump chamber (fig. 3 and 4) is underground at the dock entrance, inside one of the approach walls.

PUMP DRIVES.

The two main de-watering pumps are of the centrifugal double-entry type with horizontal spindles coupled directly to the associated 400 h.p. synchronous induction driving motors. These machines are connected to a 3,150 volt, 3-phase, 50-cycle supply and operate at unity power factor when running at a synchronous speed of 333 r.p.m. They are continuously rated for operation in an ambient temperature of 90 deg. F.

As the de-watering pumps would drive the motors in the event of a reversal of water flow, the motors are designed to withstand a speed of 450 r.p.m. in the reverse direction of rotation. A drip-proof and vermin-proof form of enclosure has been employed, the motors being mounted on bedplates and fitted with ring-lubricated journal bearings. Excitation is provided by direct-coupled exciters rated at 9·5 kW at 25 volts, and the rotor-resistance method of starting is employed.

For draining the suction chamber and culverts of the dock, two drainage pumps with a combined rating of 6,000 gal./min. at a total head of 43 ft. are installed. These are of the double-entry centrifugal type and are driven at 965 r.p.m. by vertical-spindle slipring motors with a continuous rating of 66 h.p. at 400 volts. These motors are also of drip-proof and vermin-proof construction and are fitted with end-shield bearings.

A horizontal centrifugal pump rated at 1,250 gal./min. at 80 p.s.i. feeds sea water into a high-pressure main for fire-fighting and general purposes. This pump is driven at 1,350 r.p.m. by a 110 h.p. slipring motor, similar in construction to the drainage pump motors. The rotor resistance method of starting is used for all three machines.

Squirrel cage motors with direct-to-line starters are used for the smaller auxiliary drives, which include two seepage pumps connected to a sump in the floor of the pump chamber, two exhausters for priming the main de-watering pumps, and a third exhauster for priming the drainage pumps. The seepage pump motors are 400 volt vertical-spindle machines with

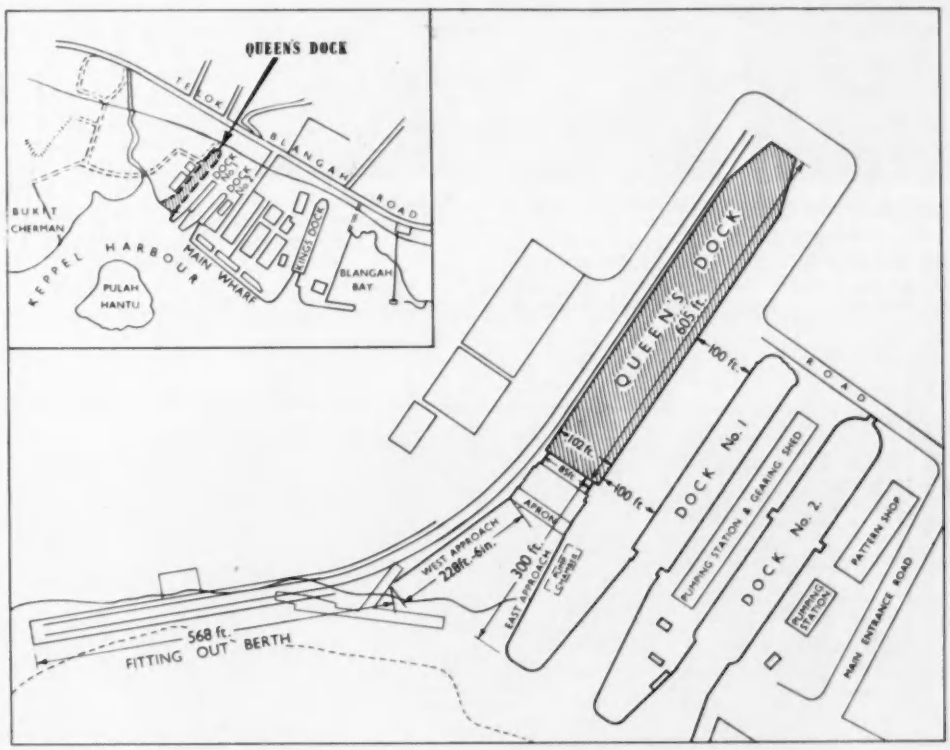


Fig. 2.—Location and dimensions of the new graving dock in Singapore Harbour.

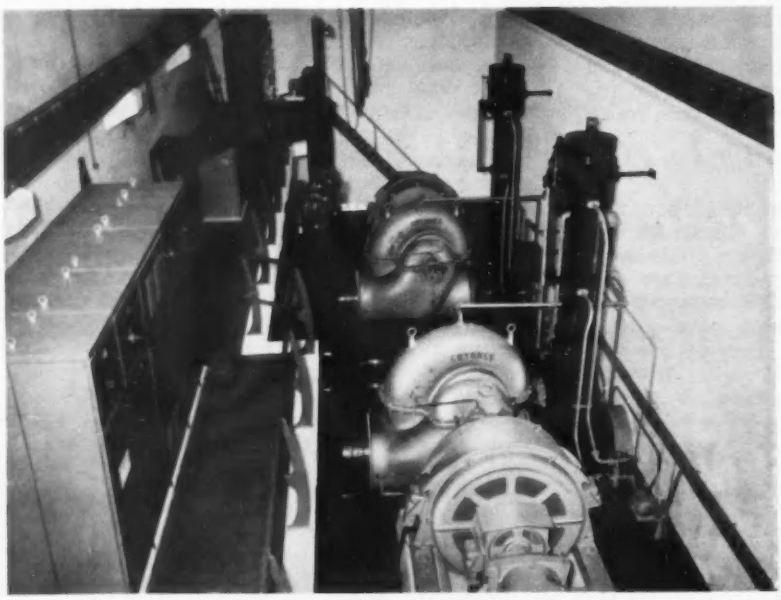


Fig. 3.—Pump chamber showing the two main de-watering pumps, starter boards and control desk.

drip-proof enclosures and a continuous rating of 3 h.p. at 940 r.p.m. The exhauster pump motors are generally similar, but are of the horizontal type, two being rated at 6 h.p. at 1,420 r.p.m. and the third at 3 h.p. at 1,440 r.p.m.

In addition to the pump drives already described, the suction and delivery valves associated with the main pumps are motor-driven and are remotely controlled. The two delivery valves are electro-hydraulic in operation, and the oil pumps supplying the hydraulic power must be kept running while the valves are open. When the oil pump motors stop, the valves are closed automatically, and a form of interlocking is provided to ensure that a valve cannot be opened until the corresponding de-watering pump is running at full speed.

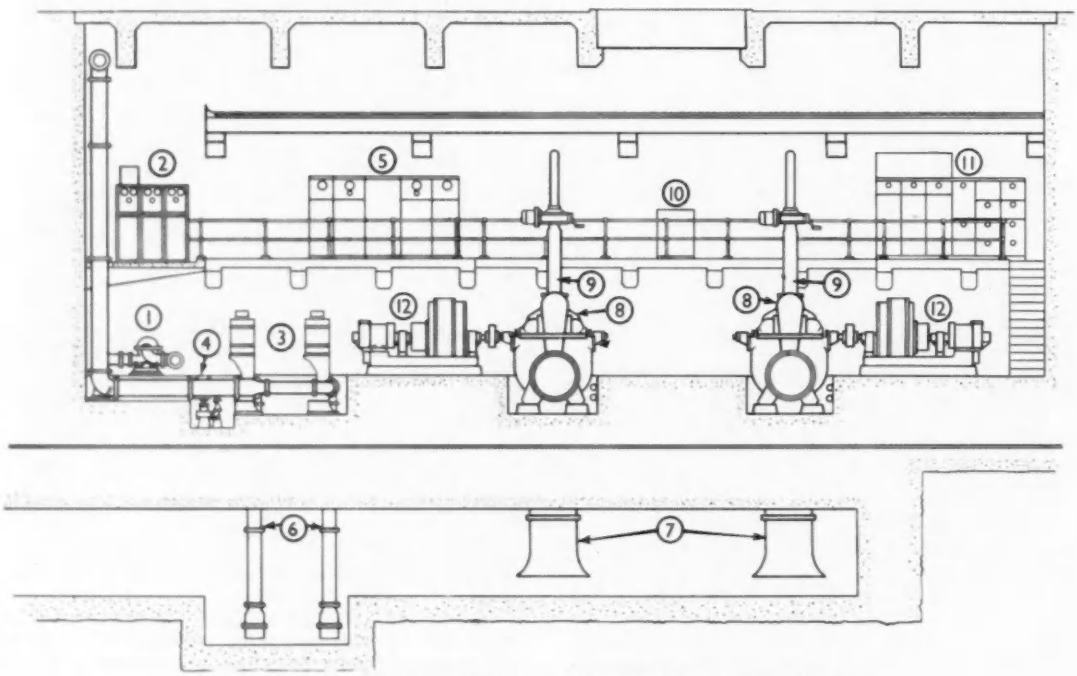


Fig. 4.—Layout of machinery and control boards in underground pump chamber.

(1) Fire pump ; (2) High-tension panel ; (3) Drainer pumps, sluice and recoil valves ; (4) Sump pumps ; (5) De-watering pump starter board ; (6) 12 in. suctions ; (7) 42 in. suctions ; (8) De-watering pumps ; (9) 42 in. electrical sluice valve ; (10) Control desk ; (11) Main 400 V starter board ; (12) Synchronous motors.

POWER DISTRIBUTION.

The incoming high-voltage supply for the main drives is controlled from a cubicle type switchboard of sheet steel construction fitted with three manually-operated oil circuit breakers of 75 MVA breaking capacity. These circuit breakers are equipped with current-transformer-operated overload trips shunted by time-limit fuses. The two outgoing circuits are connected to the main starter board, which is also of the sheet steel cubicle type and accommodates the isolators, stator contactors, accelerating contactors, starting resistors and shunt field regulators for the de-watering pump motors, together with the associated instruments and overload protection equipment. Local control facilities are provided on this board, but in normal operation the motors are remotely controlled from the main desk.

The control gear for the 400 volt motors driving the auxiliary pumps is housed, together with the starters for the motor-operated valves, in a multi-tier switchboard of sheet steel cubicle construction. Each circuit is equipped with a hand-operated air break isolator, H.R.C. fuses, instruments, start/stop pushbuttons and a local/remote control changeover switch. The starting equipment for each slipring motor comprises a double-pole rotor contactor closing under the control of a timer unit so as to short out in sequence sections of an unbreakable grid type starting resistor.

CONTROL DESK.

The main desk from which the pumps and valves are normally controlled is constructed in sheet metal with a sloping top on which are the pushbuttons and indicator lamps for the various circuits (fig. 5). The controls for all main and auxiliary pumps except the seepage pumps take the form of start/stop push-buttons with lamps to indicate whether the corresponding motor is running or stopped. The two seepage pumps are started and stopped automatically by switches operated by the rise and fall of water in the sump and, in consequence, only indicator lamps are provided on the desk for these motors. For the delivery valve oil pump motors two sets of indicator lamps are provided in addition to the pushbutton controls. These indicate whether the motor is running or stopped, and also whether the corresponding valve is open or closed. The controls for the suction valves are similar to those for the delivery valves, but in this instance a third set of lamps is provided in each circuit to show whether the valve is opening, closing or stopped. All the motors and switchboards, and the control desk are equipped with internal heaters to prevent damage from condensation.

CONSULTANTS.

Coode & Partners acted as consultants for the contract for the pumping equipment for Queen's Graving Dock. Inspection and testing of the electrical plant and equipment was carried out on their behalf by Preece, Cardew & Rider.

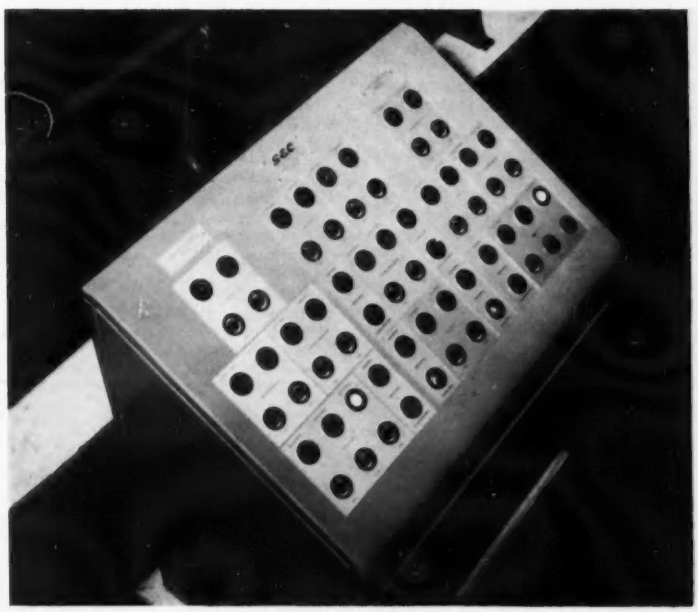


Fig. 5.—Control desk.

TECHNICAL LITERATURE

A digest of recent articles and papers by members of the G.E.C. and its associated companies

AN ULTRA-HIGH-SPEED OSCILLOGRAPH (611).*

By F. R. Connor (Research Laboratories).

Proc. I.E.E., Vol. 103, *Part B, No.* 8, *pp.* 178-181, 1956 (*Paper No.* 1931*R*, *March*, 1956).

The paper describes the design and construction of an ultra-high-speed oscillograph for observing and studying the build-up of radio-frequency oscillations of a pulsed magnetron, and other phenomena in the millimicrosecond region. It has a linear sweep-speed of 2·5 cm/mμs with a full scan of 5 cm. A special-purpose cathode-ray tube is incorporated having small plate systems. The Y-plate system is designed as a transmission line, which can be used as a resonant or non-resonant line, thus providing a means for narrow-band or broad-band matching. A unit containing short lengths of 70-ohm coaxial cable for delay purposes is included, and there is a calibrating circuit which provides a 1,250 Mc/s timing waveform from a pulsed coaxial-line oscillator which also checks the linearity of the time-base.

THE ATTACK OF UNSTRESSED METALS BY LIQUID MERCURY (621).

By J. F. Strachan and N. L. Harris (Research Laboratories).*

Journal of the Institute of Metals, Vol. 85, *pp.* 17-24, 1956-7.

The saturated solubilities and weight losses at room temperature of most of the metallic elements in static liquid mercury have been determined, usually to 0·001 per cent, by chemical analysis of the solutions and by weighing the specimens. The solubilities show a periodic relationship with the atomic number, and there are indications that this can be related to the inner electronic shell structure. In general, the solubilities of the B sub-group elements exceed those of the true metals, while of this latter group the transition metals show the lowest values.

When attack occurs, it involves wetting, surface amalgamation, solution, and occasionally combination and intergranular penetration. The effect of oxide films has been investigated.

The tests were conducted as far as possible in the absence of air, since oxidation brought some metals out of solution in mercury, leading to ambiguities. Exposure to air can result, for example, in a form of mass transfer.

No significant changes take place in the mechanical properties of iron, molybdenum, some steels, and nickel alloys after 2,000 hours in mercury at 500 deg. C. Nickel suffers a decrease in maximum stress, yield stress, and elongation of about 50 per cent.

Severe cavitation erosion of metals and alloys, normally resistant to mercury, occurs at room temperature on the application of 30 kc/s ultrasonic vibrations.

BOMBARDMENT OF VARIOUS ELEMENTS BY Hg^+ AND A^+ IONS (628).*

By J. F. Strachan and N. L. Harris (Research Laboratories).

Proceedings of the Physical Society, B, Vol. 69, *pp.* 1148-1161, 1956.

The sputtering, in low pressure discharge tubes, of carbon by Hg^+ and A^+ ions at energies from 10 eV to 20×10^3 eV was investigated by direct weight loss measurements. The commonly quoted linear variation of sputtering rate in grammes per ampere-hour held up to 2 to 3 kV, where it was replaced by a variation proportional to $(\text{voltage})^{1/2}$. Sputtering occurred at 30 volts, a value well below the usual "critical voltages" in the literature. X-rays were generated above 8 kV by the action of secondary electrons emitted from the targets. The emission from spherical targets was determined from the dimensions of the positive ion sheaths, and was initially proportional to voltage, after which the rate of increase diminished rapidly.

A brief survey of the sputtering of beryllium, aluminium, silicon, iron, nickel, copper, molybdenum, tungsten, lead and uranium indicated similar variations with voltage, and showed that the sputtering rate was roughly proportional to the $(\text{atomic weight of the target})^{1\cdot3}$ and that it increased with the heavier ion.

These empirical relations are useful for practical assessments, but not for theoretical interpretation, unless the secondary electron emission is distinguished. This was done for carbon and iron and the sputtering rate in atoms per ion s determined. The empirical relation of the form $s = \lambda \ln(V/V_0)$ was found, where V_0 is thought to be related to the "penetration" of the ion into the target, and has a value of a few hundred volts. The ratio of the binding energy of the atom to the energy required to sputter it, for carbon and iron atoms released by Hg^+ and A^+ ions, had a maximum of 0·5 per cent at 2,000 volts for carbon and 2·5 per cent at 1,000 volts for iron.

AN EXTENDED ANALYSIS OF ECHO DISTORTION IN THE F.M. TRANSMISSION OF FREQUENCY-DIVISION MULTIPLEX (632).*

By R. G. Medhurst and G. F. Small (Research Laboratories).

Proc. I.E.E., Vol. 103, *Part B, pp.* 190-198, 1956 (*Paper No.* 2006*R*, *March*, 1956).

When a frequency-division-multiplex telephony signal is subjected to some non-linear process, intermodulation distortion is generated, being usually audible as an unintelligible noise. In f.m. systems an important source of such non-linear distortion is to be found in small echoes of the main r.f. signal. Albersheim and Schafer have investigated theoretically and experimentally the distortion due to a single echo, but the analysis applied only to limited ranges of the available parameters, and the agreement with experiment was not always good. It now appears that, by a combination of analytical and semi-empirical methods, Albersheim and Schafer's result can be extended to enable prediction of distortion levels for most cases of practical interest (in the absence of pre-emphasis). Most of the discrepancy between theory and the measurements of Albersheim and Schafer can also be accounted for, the formulae being in good agreement with measurements carried out by the present authors.

SINGLE CRYSTAL BISMUTH TELLURIDE (655).*

By L. Ainsworth (Research Laboratories).

Proceedings of the Physical Society, B, Vol. 69, *pp.* 606-612, 1956.

Bismuth telluride has been investigated because of its promise as a material for thermo-electric applications. Attempts have been made to grow single crystals of the material by the Stockbarger method, by directional freezing in a horizontal boat, and by pulling from the melt. The first two methods were not found to be satisfactory because of segregation of tellurium towards the last end of the ingot to

freeze. This was particularly marked at the slow speeds of withdrawal desirable for good single crystal growth. At fast speeds of withdrawal the segregation was prevented, but at these speeds large single crystals were not produced. Larger crystals, about 1 cm × 2 cm × 3 cm were produced by the pulling method, using a hydrogen atmosphere. These were all p-type of thermo-electric power 200-215μV deg.$^{-1}$ even when considerable departures from the stoichiometric composition Bi_2Te_3 were made in the charge from which the crystals were pulled. The energy gap of this material, measured optically, was 0·15 eV. A p-type single crystal specimen of thermo-electric power 200μV deg.$^{-1}$ had a room temperature electrical conductivity of 500 Ω^{-1} cm^{-1} parallel to the cleavage planes. The room temperature thermal conductivity of the same specimen was 0·0175 w cm^{-1} deg.$^{-1}$ parallel to the cleavage planes, and 0·0076 w cm^{-1} deg.$^{-1}$ perpendicular to the cleavage planes.

THE DESIGN, CONSTRUCTION AND OPERATION OF A LABORATORY CLASSIFIER (659).*

By D. G. Armstrong (Research Laboratories).

Transactions of the Institution of Mining and Metallurgy, Vol. 65, Part 6, pp. 229-239, 1955-6.

A laboratory classifier for treating ore samples at rates up to 10 kg. per hour with an efficiency equivalent to that of a commercial rake classifier is described. Results are readily reproducible and examples of efficiency are given.

LIGHT SOURCES FOR COLOUR MATCHING (662).*

By E. E. Miles and D. C. Peach (Research Laboratories).

Transactions of the Illuminating Engineering Society, Vol. 21, No. 6, pp. 135-143, 1956.

Visual comparison of the colour of an article with a colour standard forms the basis of colour control in many industries. While the colour of the sample and the standard will only be a true match if their spectral reflectance characteristics are identical, this is not always practicable and the problem facing the colourist is to obtain the best match under the widest range of illuminants. North overcast daylight is generally regarded by colourists as being the most satisfactory source. The general characteristics of daylight with particular reference to variations in colour, the conclusions reached in surveys conducted to determine the preferred characteristics, and the variations between observers in determining a colour match are discussed. The matching of colours having a fluorescent component and the matching of fluorescent whites are also discussed. Artificial light sources which are available for colour matching work are compared. A source combining tungsten filament and fluorescent lamps which reproduces the required conditions is proposed.

CURRENT DERIVED RESISTANCE-CAPACITANCE OSCILLATORS USING JUNCTION TRANSISTORS (665)*

By D. E. Hooper and A. E. Jackets (Research Laboratories).

Electronic Engineering, Vol. 28, pp. 333-337, August, 1956.

The basic criteria of resistance-capacitance oscillators are discussed. Two particular circuits, one employing a 180° phase shift and the other a 0° phase shift, are considered. Most of the circuits use G.E.C. type EW59 transistors. The oscillators using 180° phase shift networks have the advantage of simplicity and the use of only one transistor, but cannot be used at frequencies in excess of a few kilocycles per second. These oscillators may, however, be used to produce stable outputs having frequencies of a fraction of a cycle per second. The oscillator using the 0° phase shift network allows a maximum frequency of about 30 kc/s to be reached at the expense of an extra transistor and more complicated circuits. Due to the resistance-capacitance coupling within the two-stage amplifier, this type of circuit will not function at frequencies of the order of a fraction of a cycle per second. Subject to certain frequency limitations, which are discussed, and also to some "impedance discontinuity" conditions, either of these two circuit types can be designed to give good performance.

THE USE OF ETHYLENE DIAMINE TARTRATE FOR PIEZO-ELECTRIC FILTER ELEMENTS (670).*

By J. Birch, A. G. Frith, A. C. L. Ferguson, R. H. A. Miles and J. F. Werner (Research Laboratories).

Proc. I.E.E., Vol. 103, Part C, No. 4, pp. 420-427, 1956 (Monograph No. 182R, June, 1956).

Crystal resonators suitable for use in telephone system channel filters have been made from ethylene diamine tartrate (e.d.t.). Methods used in the fabrication and mounting of these units are described. The circuits used in the determination of the electrical parameters are given, and the results of a large number of measurements are outlined. Freedom from unwanted resonances over the desired frequency bands combined with the required characteristics has been achieved by suitably dimensioning the plates, and by applying electrodes to a part of the crystal surface only. Increased activity for crystals mounted in air can be obtained by the use of suitably placed reflectors.

THE SOLUTION OF ELECTRIC FIELD PROBLEMS USING A DIGITAL COMPUTER (672).*

By J. H. Wensley and F. W. Parker (Research Laboratories).

Electrical Energy, Vol. 1, pp. 12-16, September, 1956.

A programme for a digital computer is described enabling the electric potential to be found within a structure possessing axial symmetry, and within which materials having different dielectric constants exist. An example is given, and the time taken for the programme to obtain the solution is quoted for a variety of cases. The rate of convergence of the method used is discussed.

RELATIVE BRIGHTNESS OF COLOURED LIGHT SOURCES (674).*

By H. M. Ferguson and W. R. Stevens (Research Laboratories).

Transactions of the Illuminating Engineering Society, Vol. 21, No. 9, pp. 227-247, 1956.

Experiments in the laboratory to compare the apparent brightness of mercury and sodium light sources of high luminance show that most observers do not judge brightness on the ordinary photometric scale. In some circumstances the mercury luminance must be reduced to one third that of the sodium before observers, on balance, judge them to be equally bright.

Similar, but less marked, results were found in a formal street lighting test, a mercury installation being judged more glaring than a sodium. This, however, did not produce a marked preference for the sodium installation.

The commonly expressed preference for sodium street lighting may be partly explained by the reduced glare from sodium sources as compared with mercury but, it appears, is largely due to the characteristics of lanterns and installations now in use.

PROPERTIES OF SYNTHETIC QUARTZ OSCILLATOR CRYSTALS (675).*

By C. S. Brown and L. A. Thomas (Research Laboratories).

I.E.E. Monograph No. 205R, October, 1956.

A process for the growing of quartz crystals artificially is briefly described. This so-called synthetic quartz, which is being grown reproducibly as well-formed crystals weighing

about 135 grammes, possesses electrical and mechanical properties which closely follow those of the natural Brazilian quartz commonly used for piezo-electric purposes. The high overall quality of synthetic quartz, its freedom from twinning and other faults and its regular shape and size make it a convenient material to handle with the minimum of wastage.

Measurements have been carried out to compare the properties of oscillator crystals cut from natural and synthetic quartz. The behaviour of the AT- and BT-cuts has been investigated thoroughly, while some results have also been obtained on units of the CT-, DT- and 5° X-cuts. Most of the parameters measured show no appreciable difference between the values for natural and synthetic quartz. Two notable exceptions are a small difference in the frequency/temperature characteristics of AT-cut units, whether operated at fundamental or at overtone frequencies, and an apparently reduced activity of face-shear-mode units of the CT- and DT-cuts from the synthetic material.

The significance of these results is discussed, together with the possibility of more accurate measurements to compare the intrinsic mechanical losses in natural and synthetic quartz.

DISTORTION IN FREQUENCY-MODULATION SYSTEMS DUE TO SMALL SINUSOIDAL VARIATIONS OF TRANSMISSION CHARACTERISTICS (677).*

By R. G. Medhurst and G. F. Small (Research Laboratories).

Proceedings of the Institution of Radio Engineers, Vol. 44, *No.* 11, *pp.* 1608-1612, *November*, 1956.

It is shown that the distortion generated in F.M. systems by small sinusoidal ripples on either group delay or amplitude characteristics can be evaluated in terms of the distortion due to a single echo. Using results already established for echo distortion, curves are plotted relating intermodulation distortion of a frequency-division-multiplex signal to the amplitude, periodicity, and location of the small sinusoidal ripple for a 600-channel system. These curves are of value in estimating permissible limits of variation of transmission characteristics over the significant R.F. band.

LIFTING BY ELECTRIC MAGNETS.*

By Donald Amies (Witton-Kramer Works).

Electrical Times, Vol. 130, *pp.* 193-196, *August* 9, 1956.

The three main types of lifting magnet in general use are briefly explained followed by a comparison of the advantages and disadvantages of bolted and welded construction. Notes are given on coil construction with particular reference to the use of aluminium. Factors which influence the selection of a magnet for any particular duty follow, and the article concludes with descriptions of some of the more interesting applications of lifting magnets.

PRINCIPLE AND ANALYSIS OF A STABILISED PHASE MULTIPLIER TYPE OF MAGNETIC FREQUENCY CONVERTER.*

By E. Friedlander (Consulting Engineer, Witton Engineering Works).

Electrical Energy, Vol. 1, *pp.* 55-60, *October*, 1956.

It is shown how static frequency multiplication is achieved for odd multiples n of the network frequency by phase multiplication using n saturable reactors. Stabilisation of the primary magnetising current against variations of the supply voltage is possible by means of shunt capacitors and input reactors. The approximate size of the equipment needed for a given output and multiplication factor is derived.

HIGH VOLTAGE BUSHINGS.

By J. S. Cliff (Switchgear Works, Witton).

Electrical Journal, Vol. 157, *No.* 22, *pp.* 1578-1581, *November* 23, 1956.

The article gives details of the revision of B.S.223 published in 1956, comparing it with the earlier edition of 1931.

DIRECT ROTOR COOLING.*

By V. Easton (Witton Engineering Works).

Electrical Energy, Vol. 1, *pp.* 51-54, *October*, 1956, *and pp.* 88-93, *November*, 1956.

The application of the principle of heat transfer direct from the rotor windings to the cooling gas, and the increase in the absolute pressure of the latter, has resulted in one of the major advances in the design of turbo-alternators. It has permitted large reductions to be made in the dimensions of current units and has raised appreciably the maximum output of individual alternators on the basis of present materials. In the last few years a number of different arrangements and methods of construction have been described and it is apparent that at the present time it is being universally adopted as the best means of improving the heat dissipation of turbo rotors. The various factors involved in design are discussed and a qualitative assessment and comparison of the several schemes is given.

IMPULSE VOLTAGE STRENGTH OF OIL-IMMERSED INSULATION.

By H. F. Jones (Witton Laboratories).

Electrical Energy, Vol. 1, *pp.* 102-108, *December*, 1956.

This article describes a series of investigations to determine the behaviour of various arrangements of oil-immersed insulation when subjected to steep-fronted uni-directional impulse voltages. These include rod/rod, rod/plane, parallel cylindrical electrode gaps and various combinations of pressboard and paper wrapped conductors, being representative of the insulation used in modern high-voltage equipment.

IMPULSE TESTING OF SWITCHGEAR.

By H. F. Jones (Witton Laboratories).

Electrical Review, Vol. 157, *pp.* 303-308, *August* 17, 1956.

The requirements of modern insulation systems used in high-voltage switchgear, to meet the basic impulse levels now mandatory in many cases, are discussed.

The use of the electrolytic analogue to determine initial impulse voltage distribution in complex bushing and spout configurations is described, also the use of ionisation detectors to determine the beginning of incipient insulation failure when subjected to very high impulse voltage stresses.

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